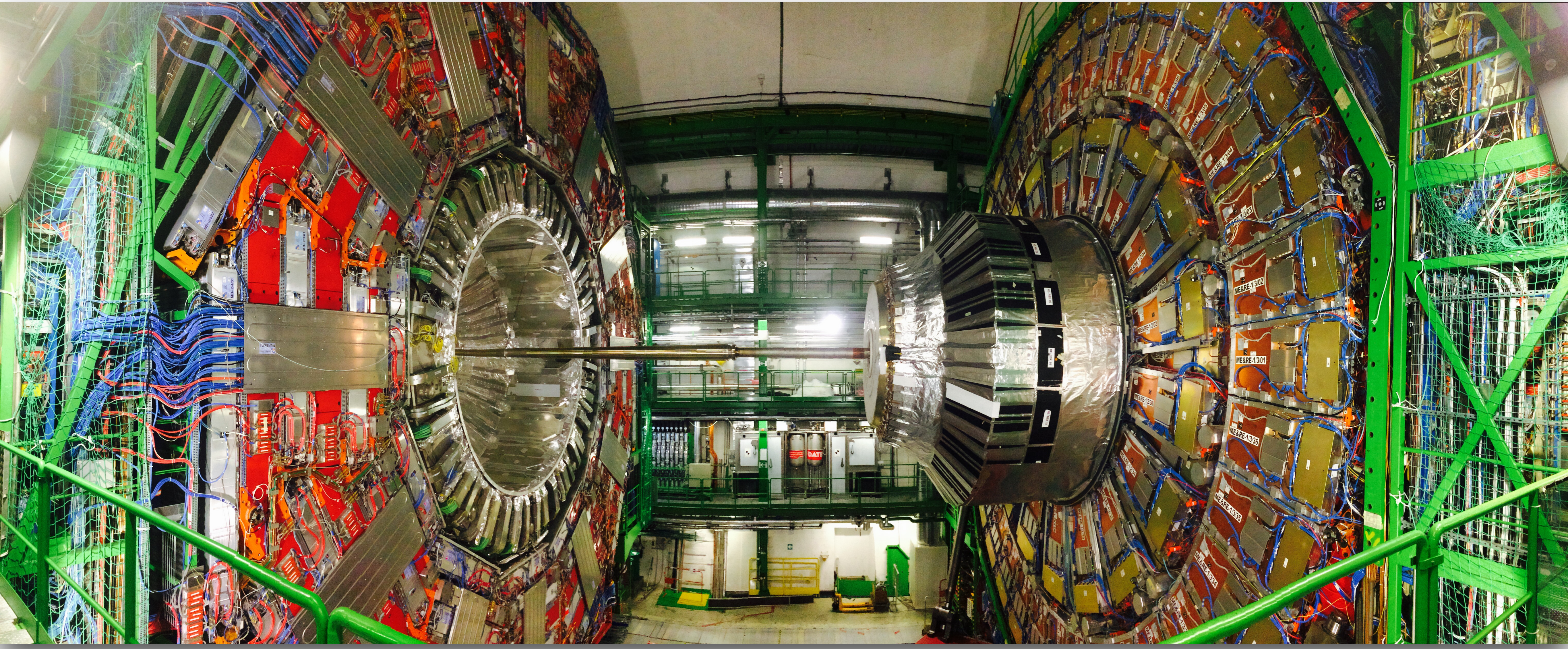
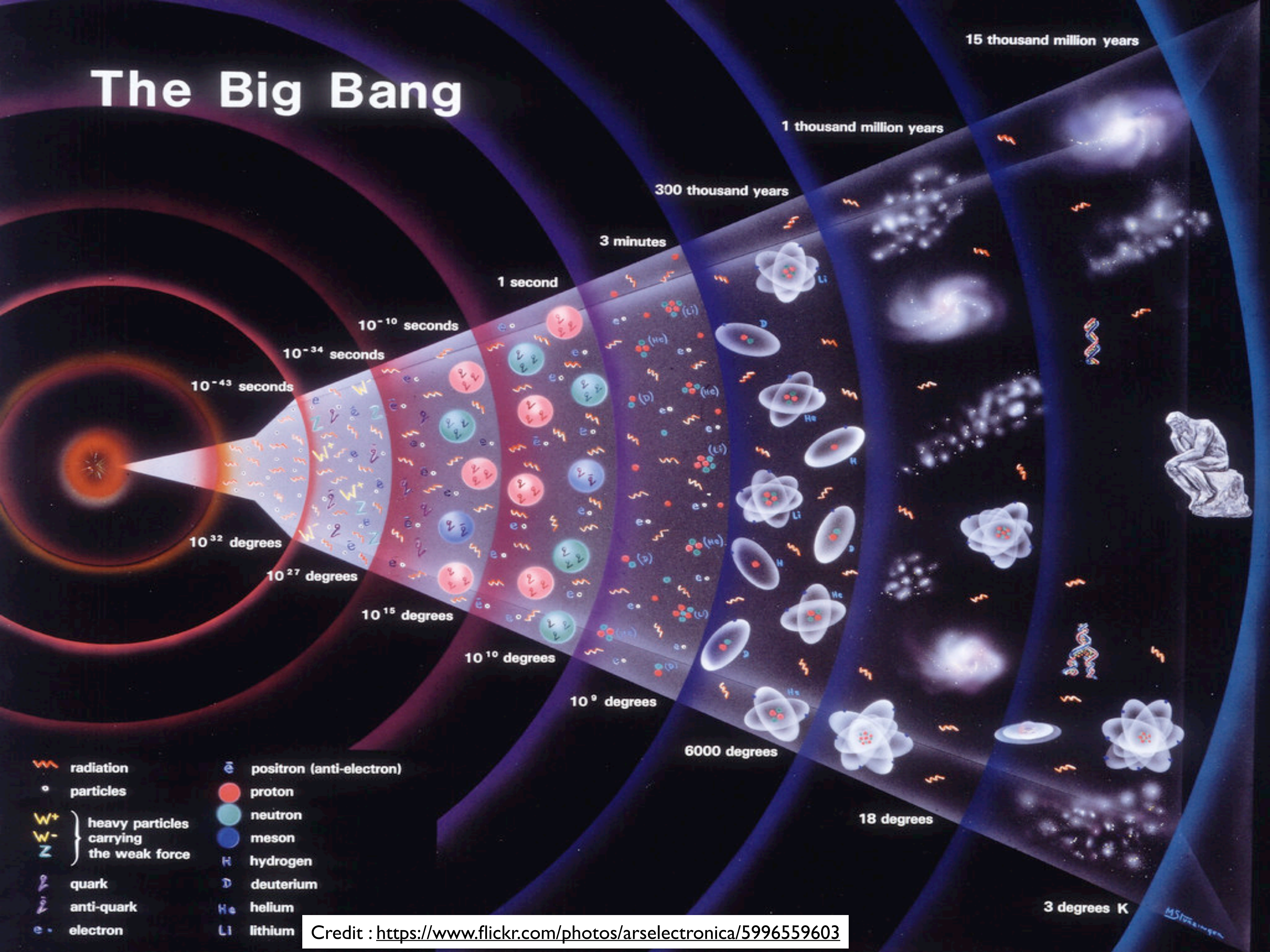


How do we detect particles?

Dr. Chayanit Asawatangtrakuldee (Aj Nan)
Chulalongkorn University

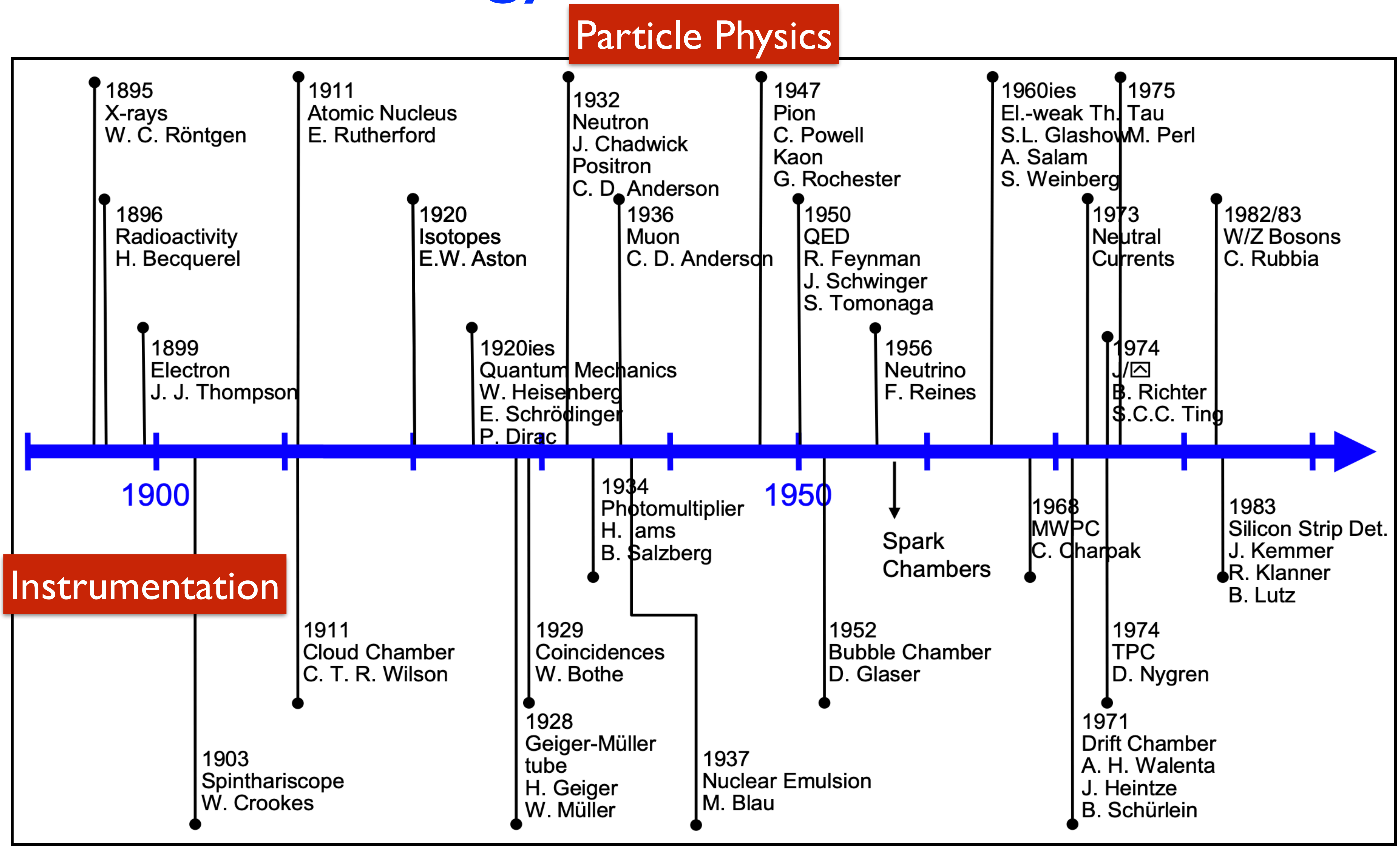


Credit : https://www.flickr.com/photos/arselectronica/5996559603

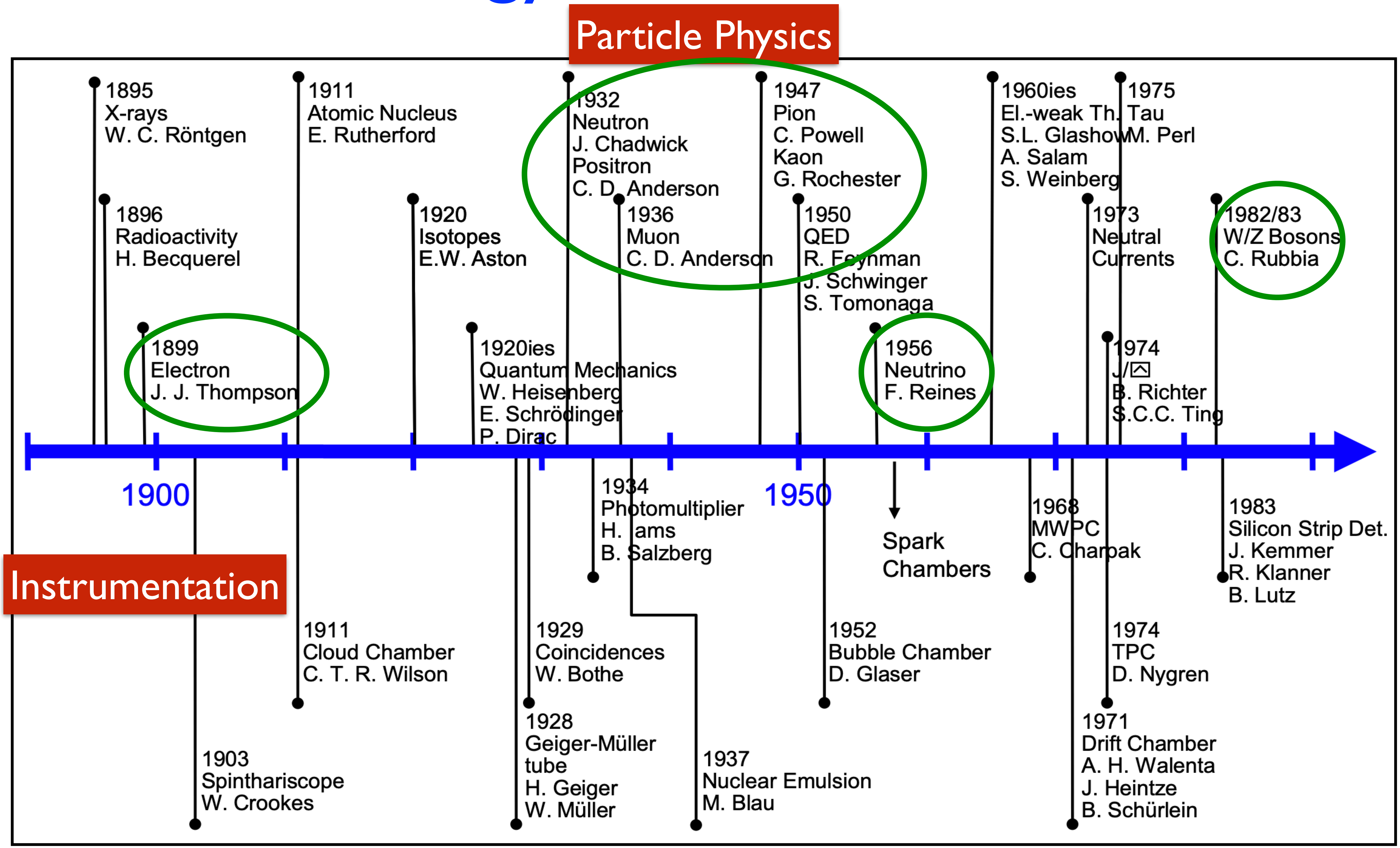
How a Detector works

"Just as hunters can identify animals from tracks in mud or snow, physicists identify subatomic particles from the traces they leave in detectors"

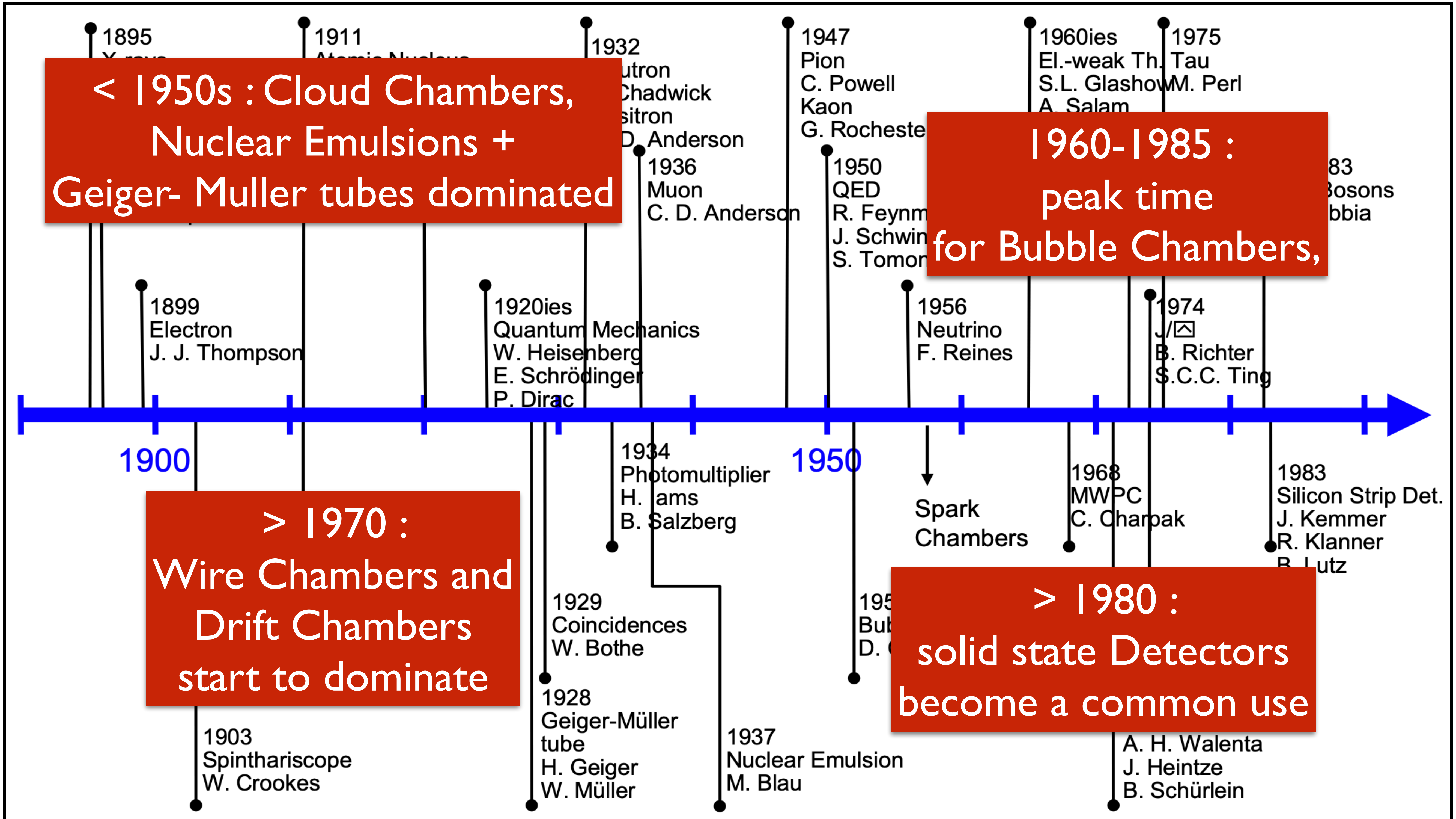
A Chronology



A Chronology

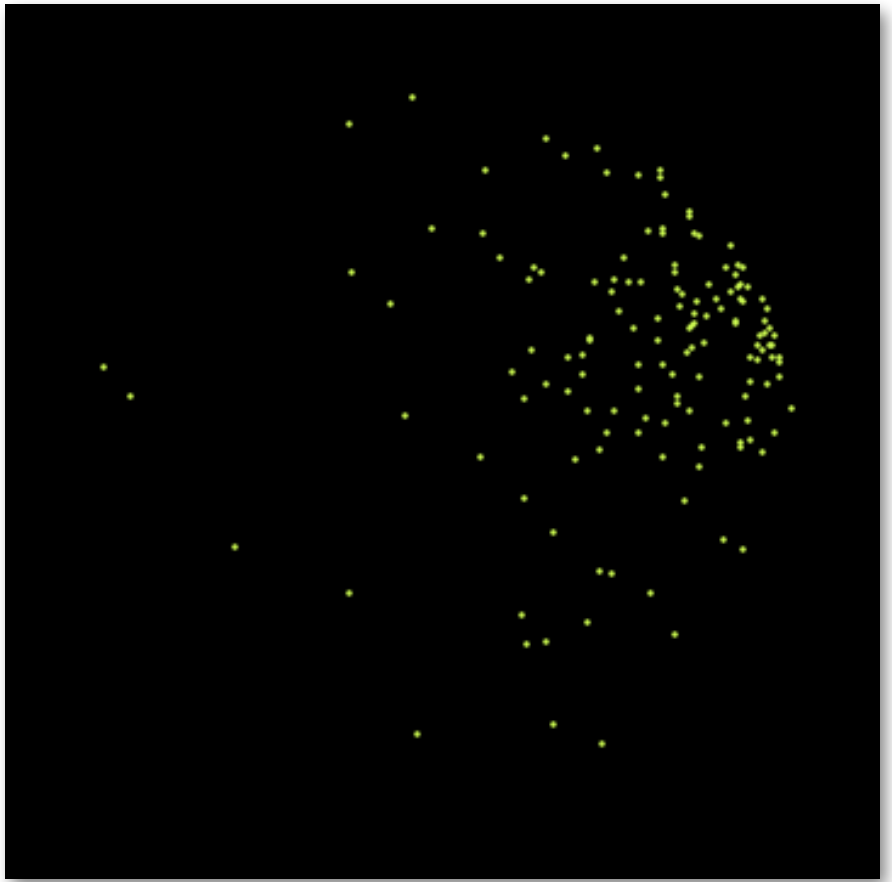


A Chronology



Spinthariscope (1903)

★ The spinthariscope, invented and beautifully named by William Crookes in 1903, is a device for seeing individual atoms or at least, seeing the death of individual atoms



★ Consist of a small screen coated with zinc sulfide affixed to the end of a tube, with a tiny amount of radium salt suspended a short distance from the screen and a lens on the other end of the tube for viewing the screen. Crookes named his device after the Greek word 'spintharis', meaning "a spark"

Credit : https://blog.wolfram.com/2007/10/30/a-thousand-points-of-light/

Spinthariscope (1903)

★ The spinthari
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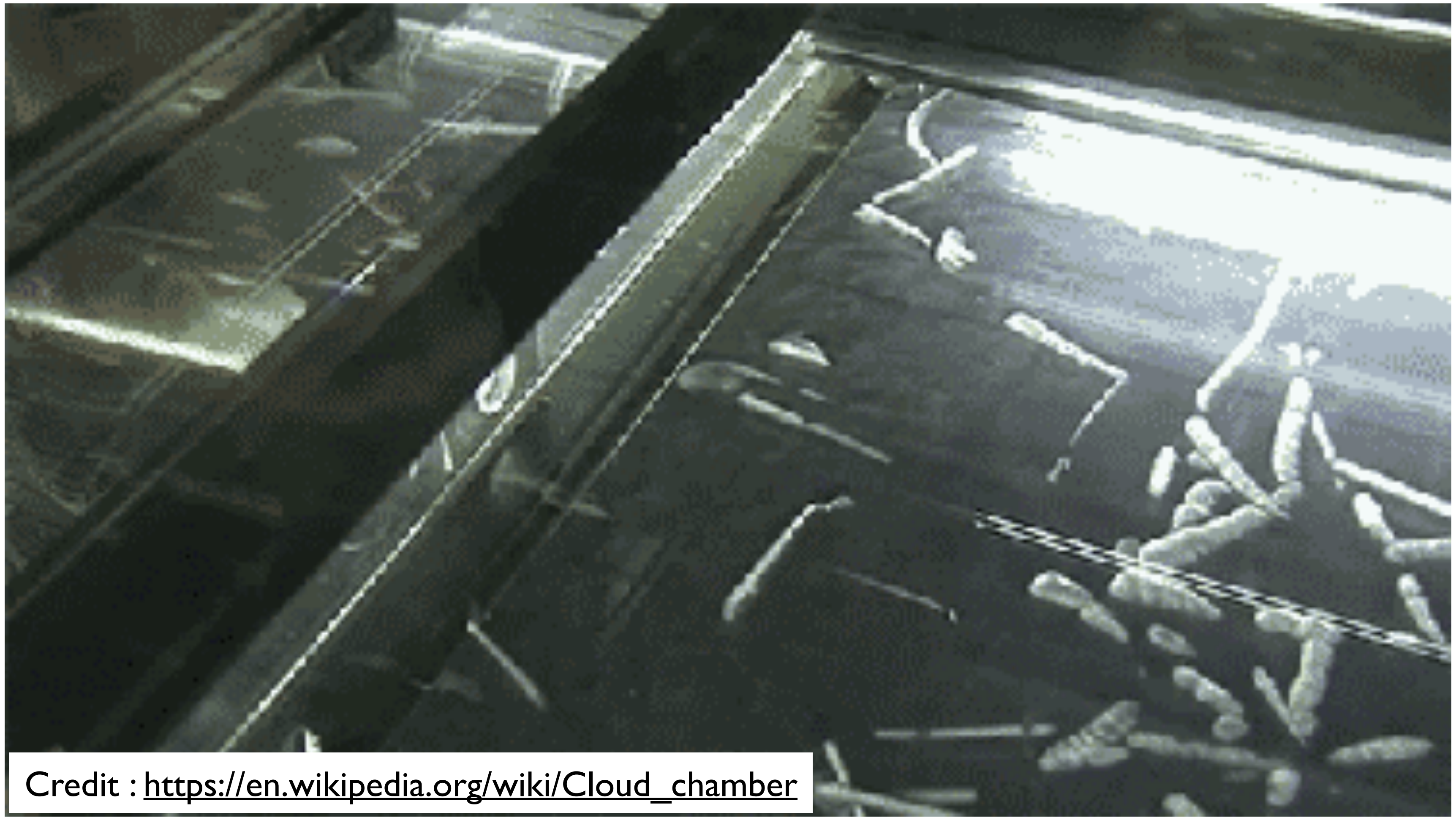
Credit : https://blog.wolfram.com/2007/10/30/a-thousand-points-of-light/

Cloud Chamber (1911)

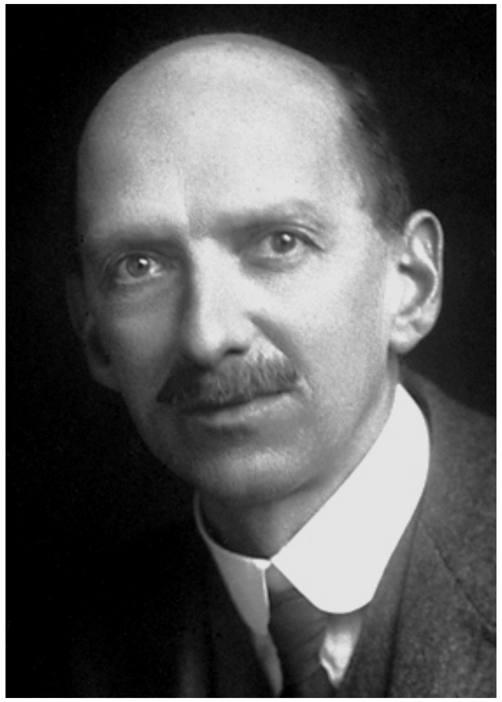
★ Originally developed to study formation of rain clouds

★ Passage of charge particle would condense the vapour into tiny droplets, making the particle's path → their number being proportional to dE/dx

★ The discoveries of positron in 1932 and muon in 1936, both by Carl Anderson (awarded a Nobel Prize in Physics in 1936), used cloud chambers

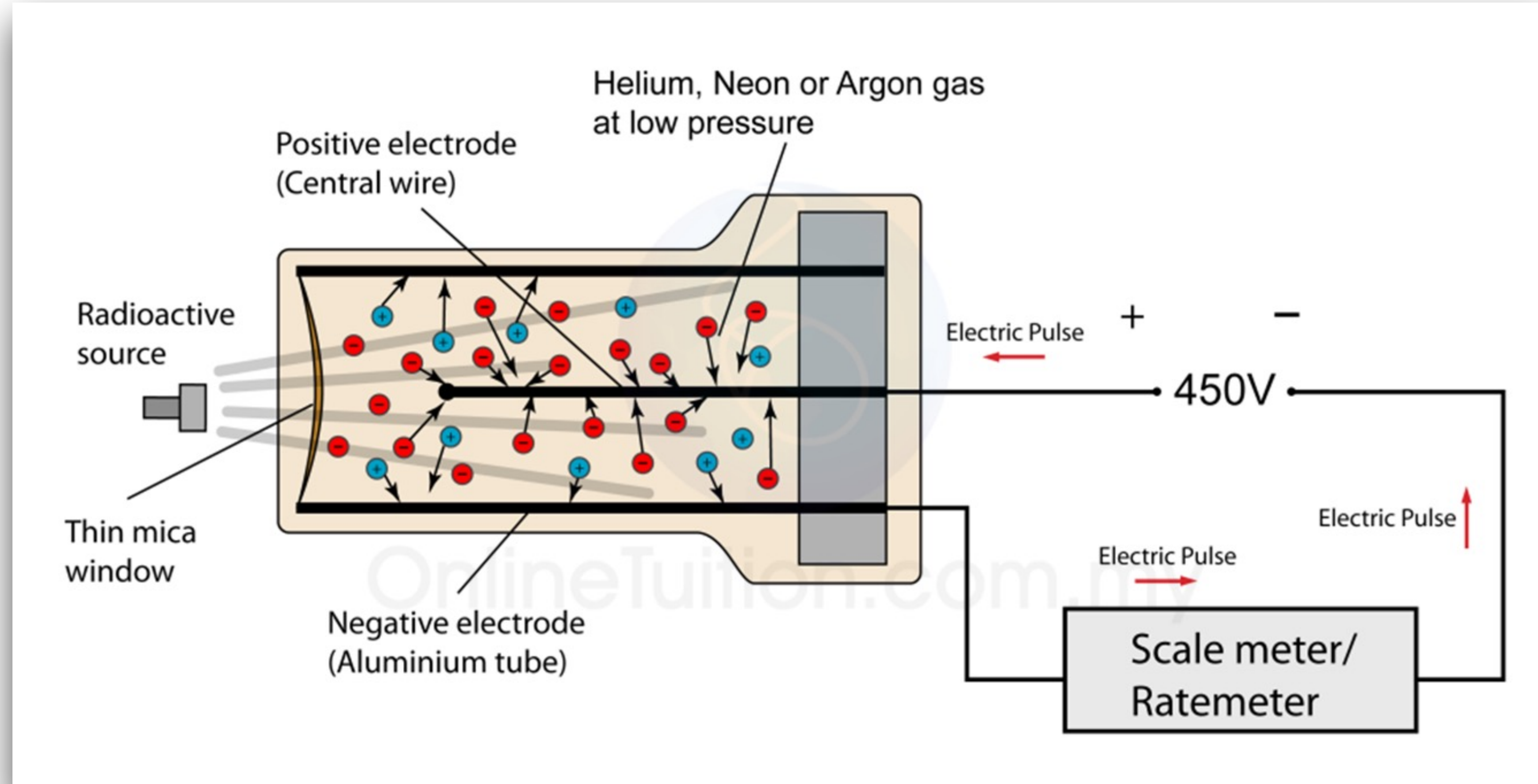


Credit : https://en.wikipedia.org/wiki/Cloud_chamber



Charles Thomson Rees Wilson
(1869–1959)
Nobel Prize in 1927

Geiger–Müller Tube (1928)



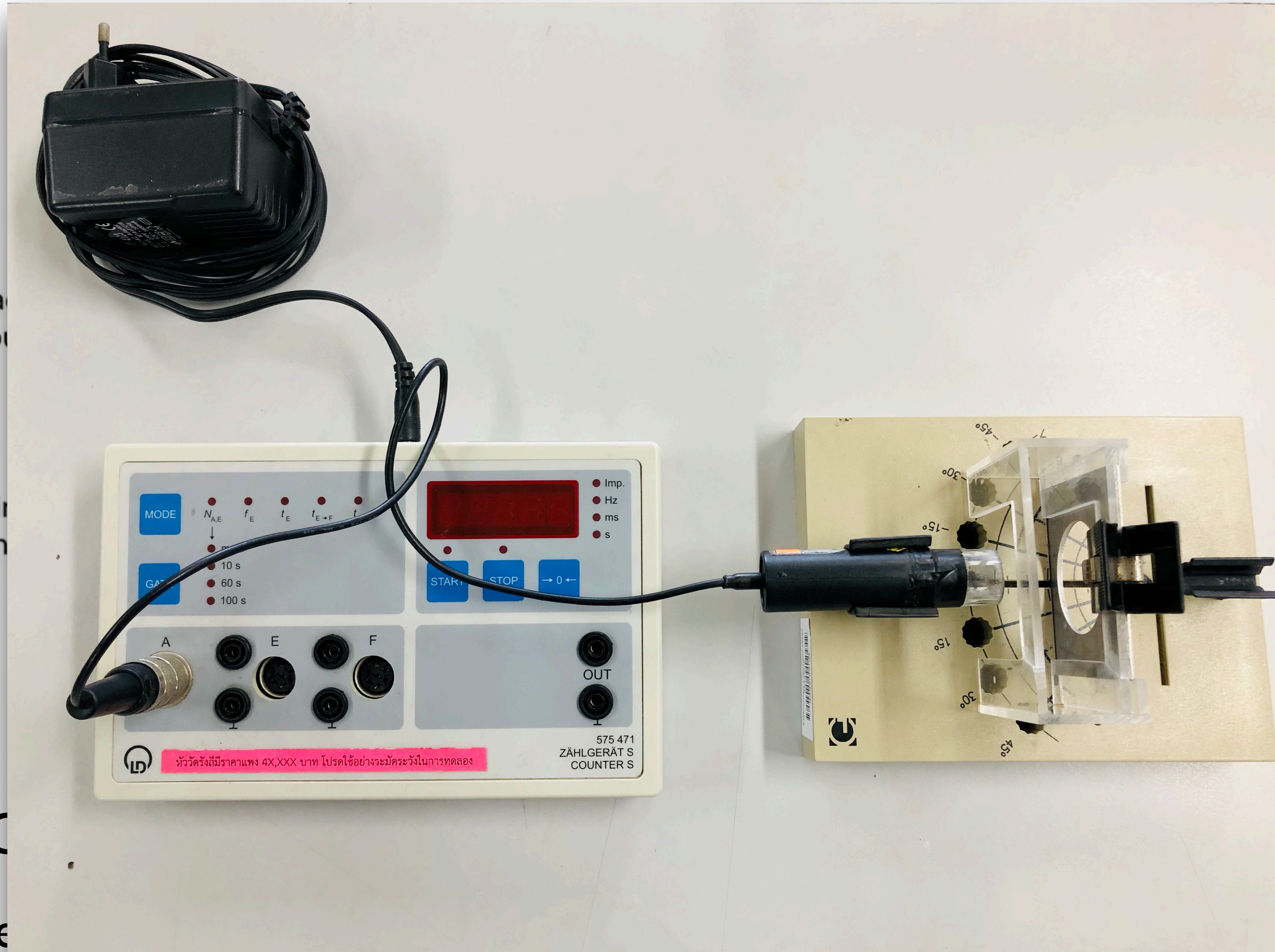
★ The Geiger-Müller tube (1928 by Hans Geiger and Walther Müller)

- Tube filled with inert gas (He, Ne, Ar) + organic vapour (alcohol)
- Avalanche process : exponential increase of electrons (and ions)

Geiger–Müller Tube (1928)

Ra
sou

Thi
win



★ The G Müller)

- Tube
- Avalanche process : exponential increase of electrons (and ions)

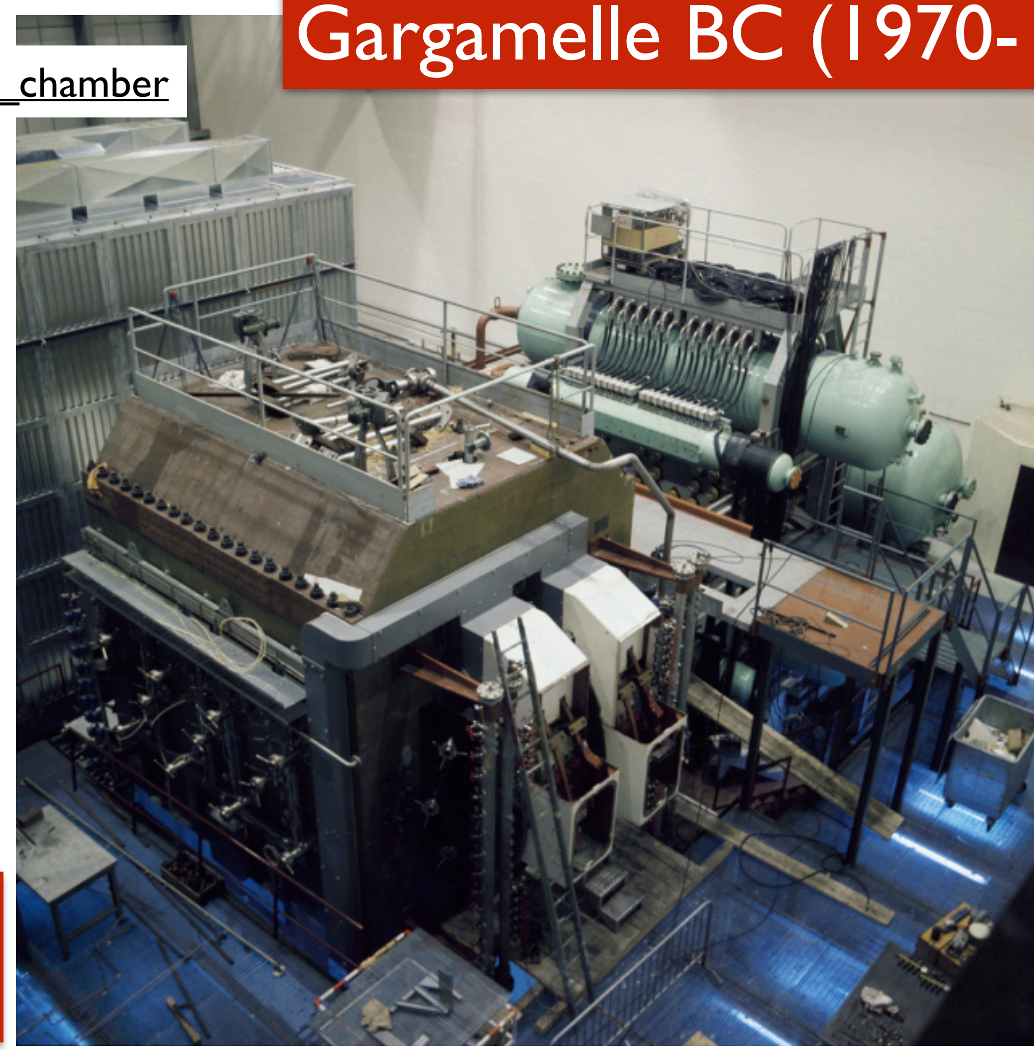
Bubble Chamber (1952)

- ★ Similar principle as cloud chamber
  - ◉ Instead of supersaturating a gas with a vapour one would superheat the liquid
  - ◉ A particle leave a trail of ions along its path → make a liquid boil and form gas bubbles around ions

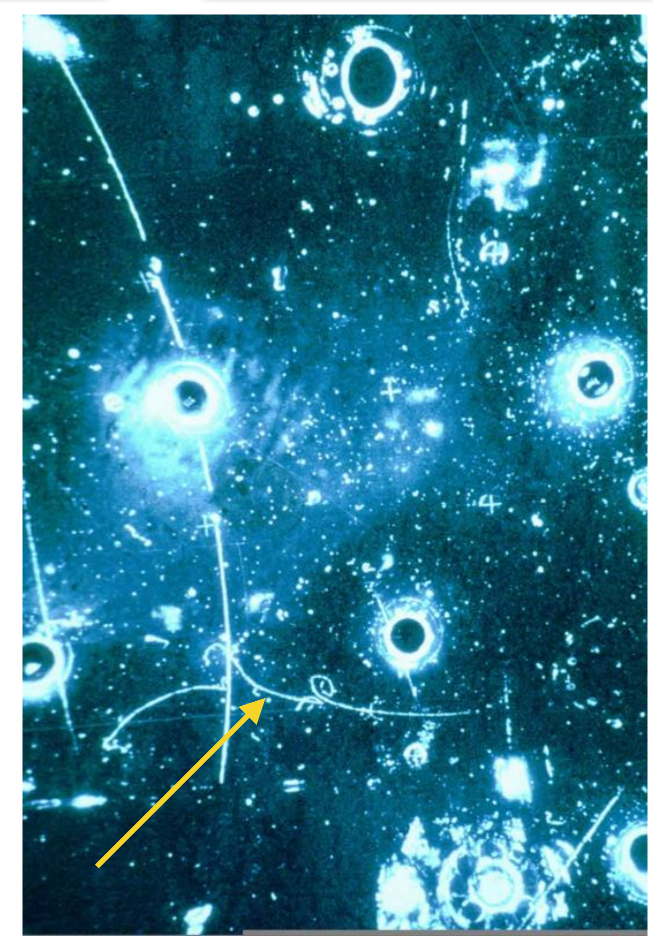
Donald A. Glaser
Nobel Prize in 1960

Credit : https://en.wikipedia.org/wiki/Bubble_chamber

Big European Bubble Chamber (BEBC) 1973-1984



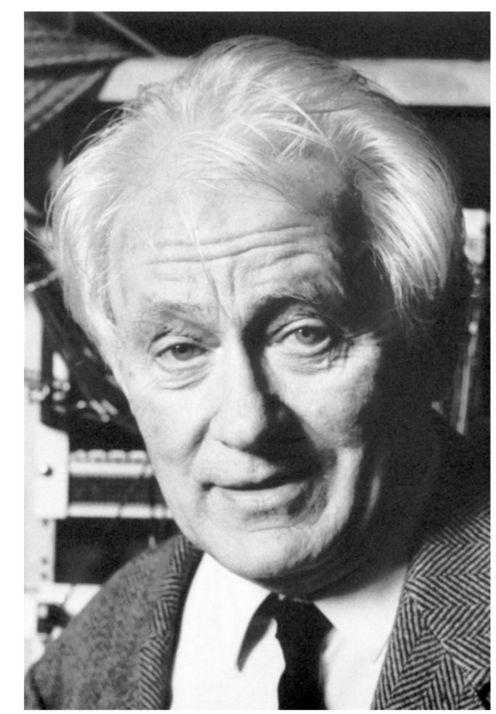
Gargamelle BC (1970-1979)



MWP Chambers (1968)

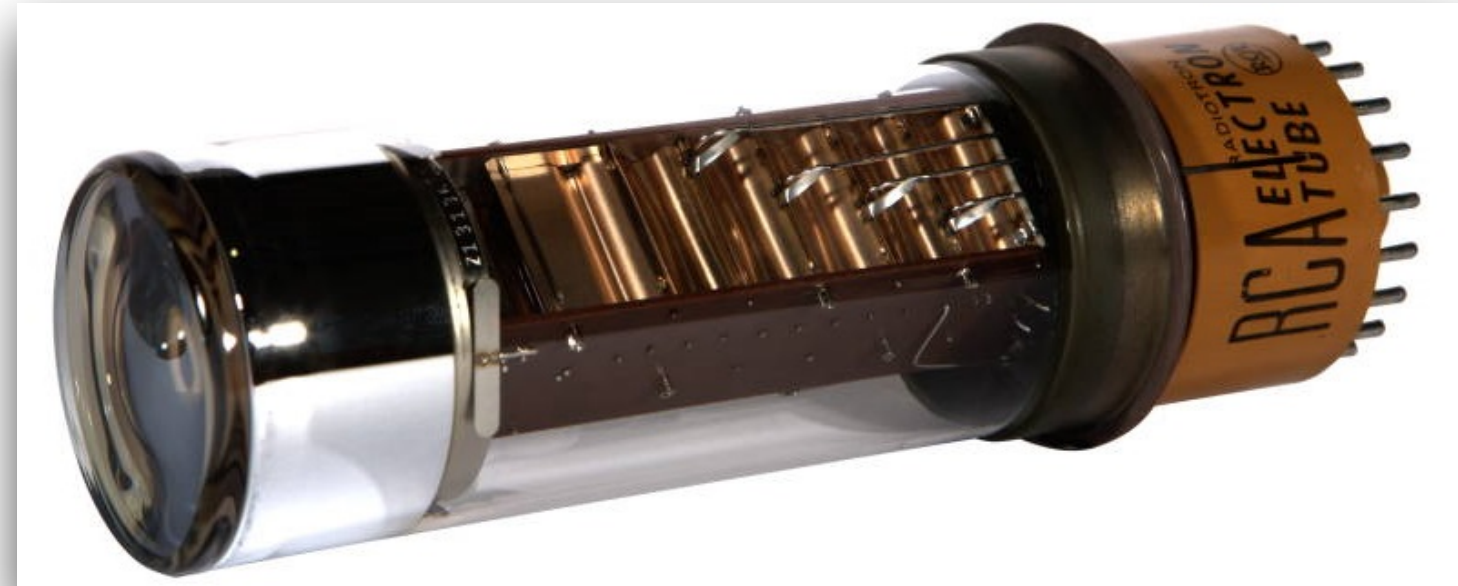
★ Multi Wire Proportional Chambers (MWPC)

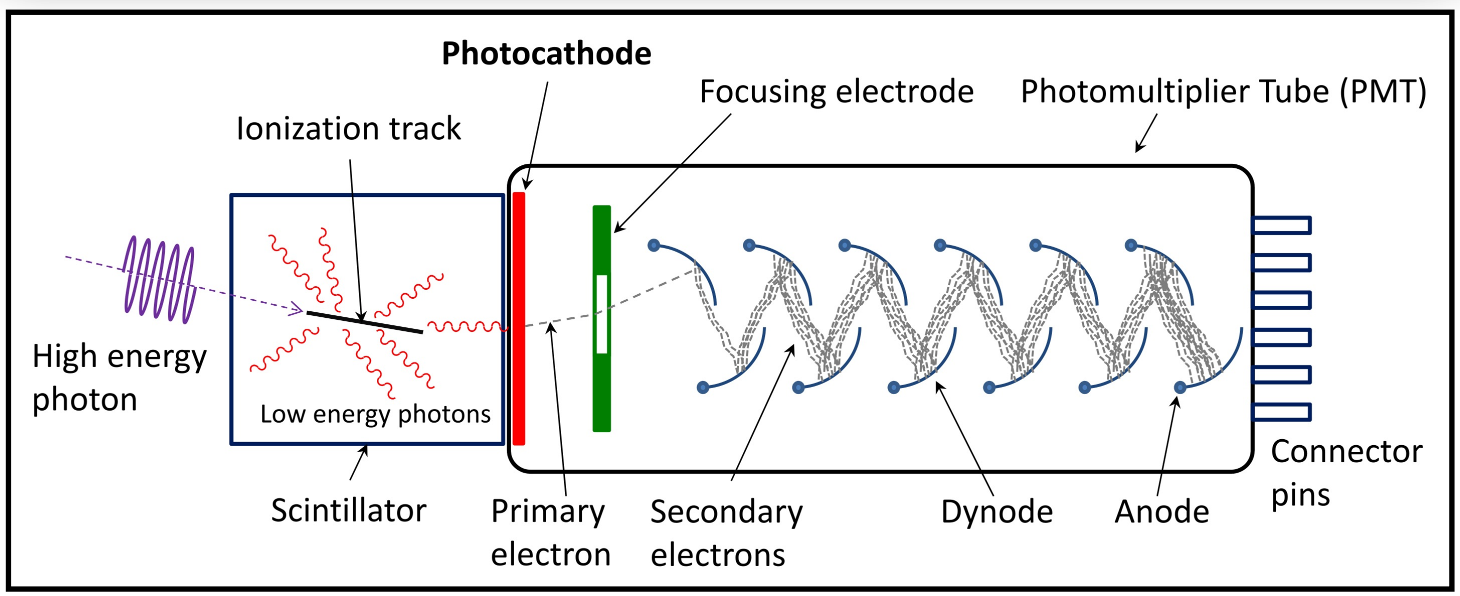
Credit : https://home.cern/news/news/experiments/fifty-years-charpak-revolutionised-particle-detectors



Georges Charpak
(1924–2010)
Nobel Prize in 1992

Some more…

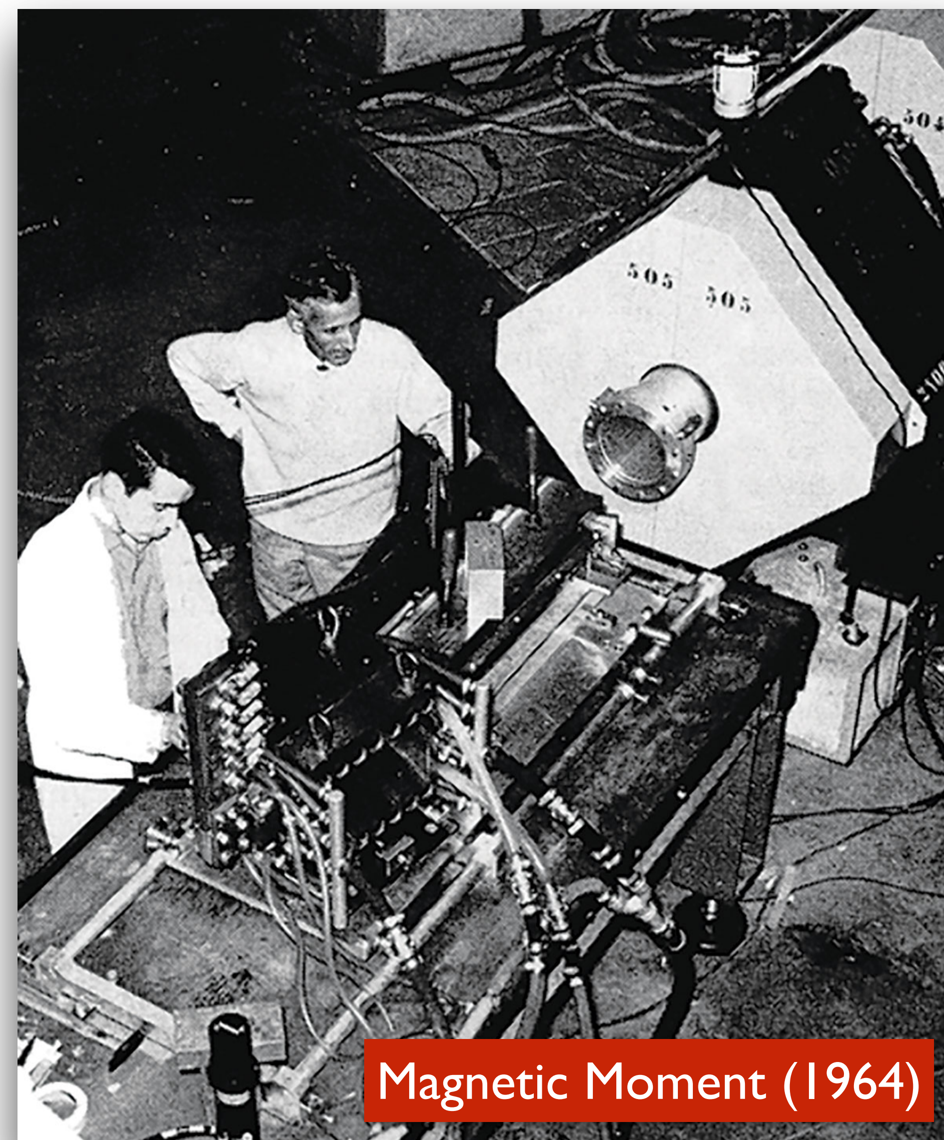




Photomultiplier tube
Harley Iams and Bernard Salzberg (1934)

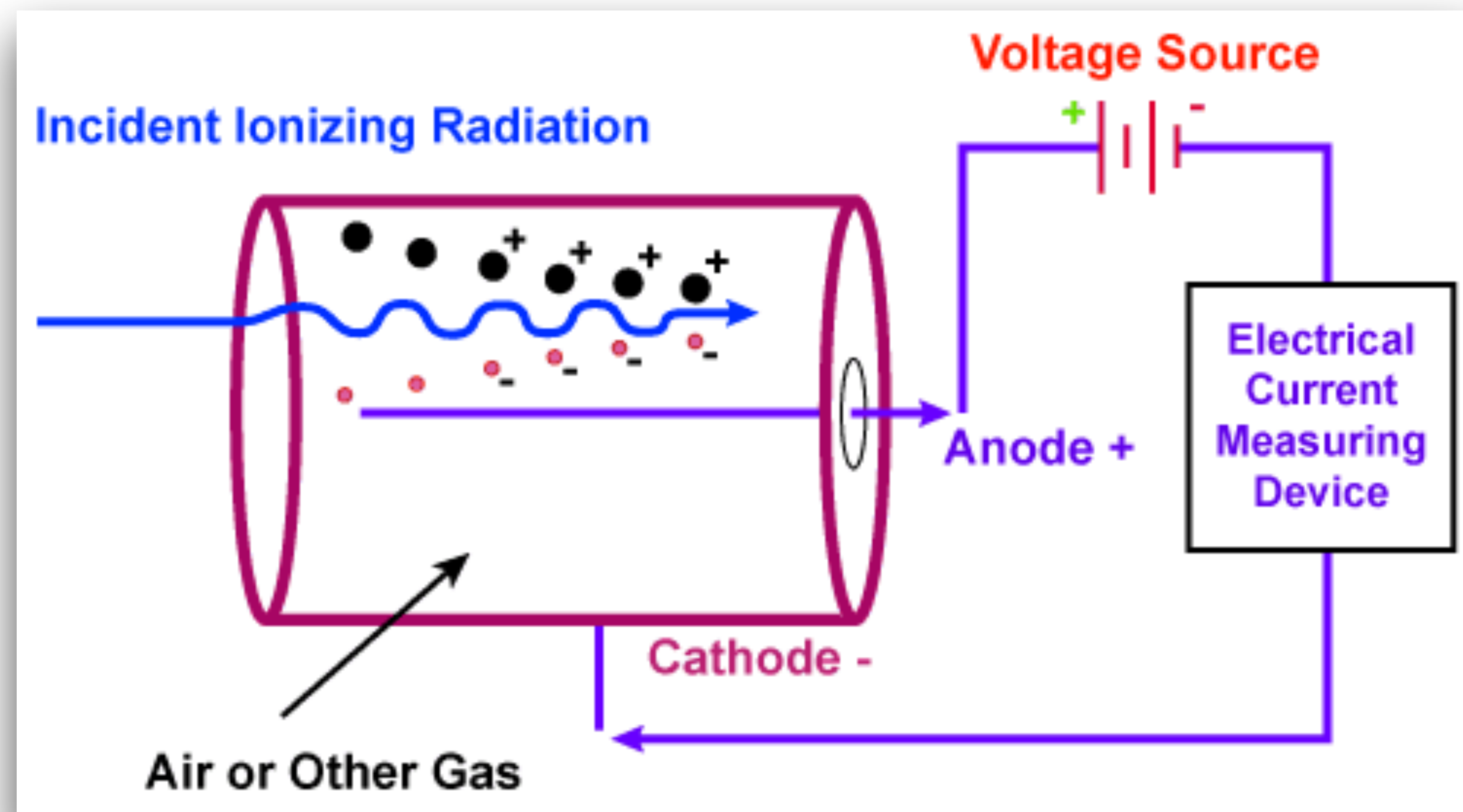
Nuclear Emulsions
Marietta Blau (1937)

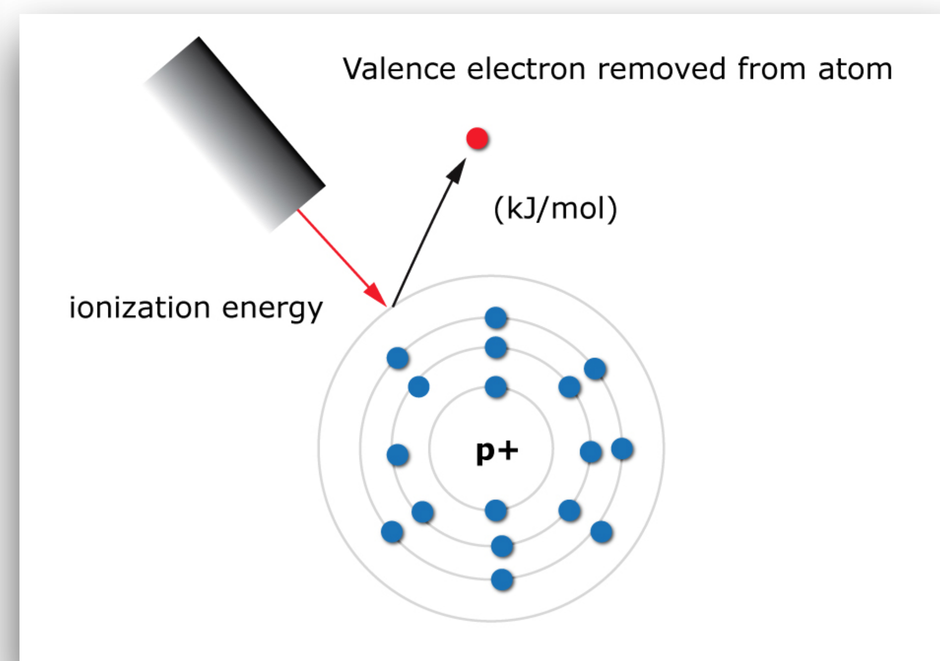
Credit : https://cerncourier.com/a/nuclear-emulsions/



Types of Particle Detector

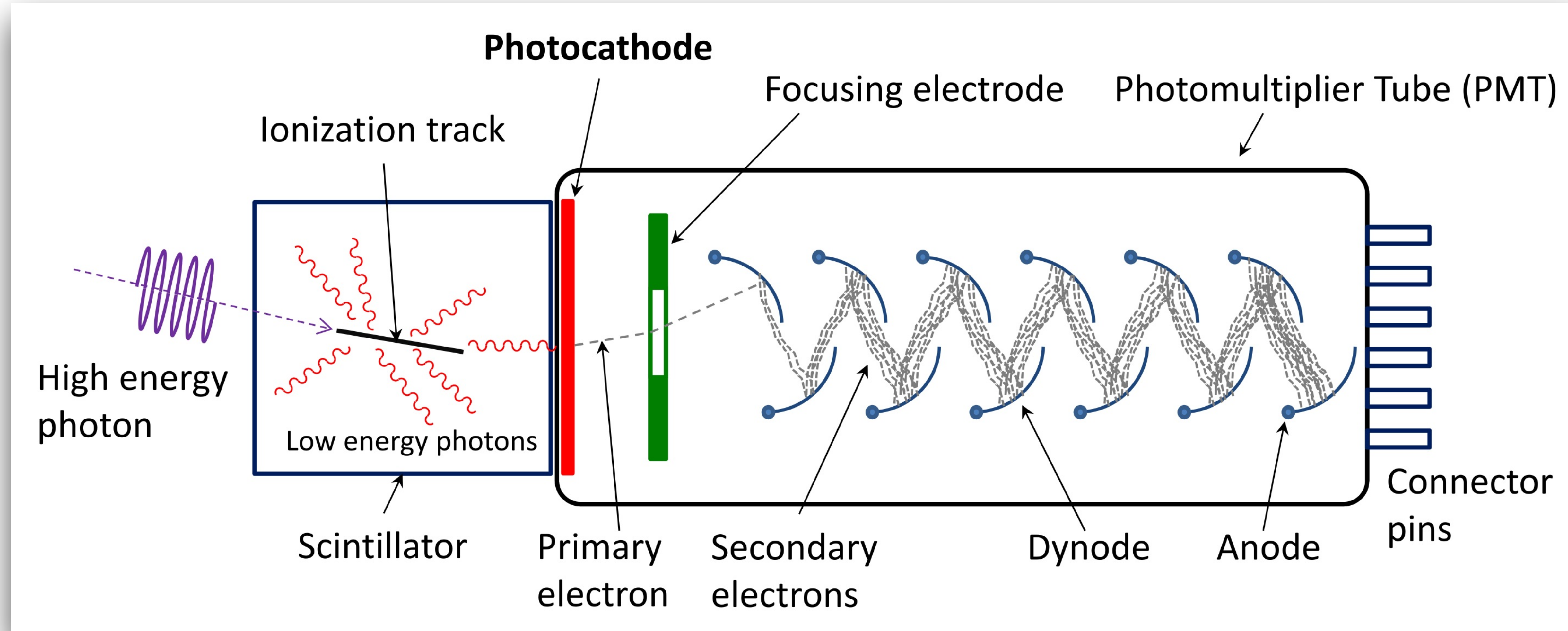
★ **Ionization detectors** : charged particle traversing matter leave excited atoms, electron-ion pairs (gases) and electrons-hole pairs (semiconductors). By applying an electric field in the detector volume, the ionization electrons and ions can be collected on electrodes and readouts





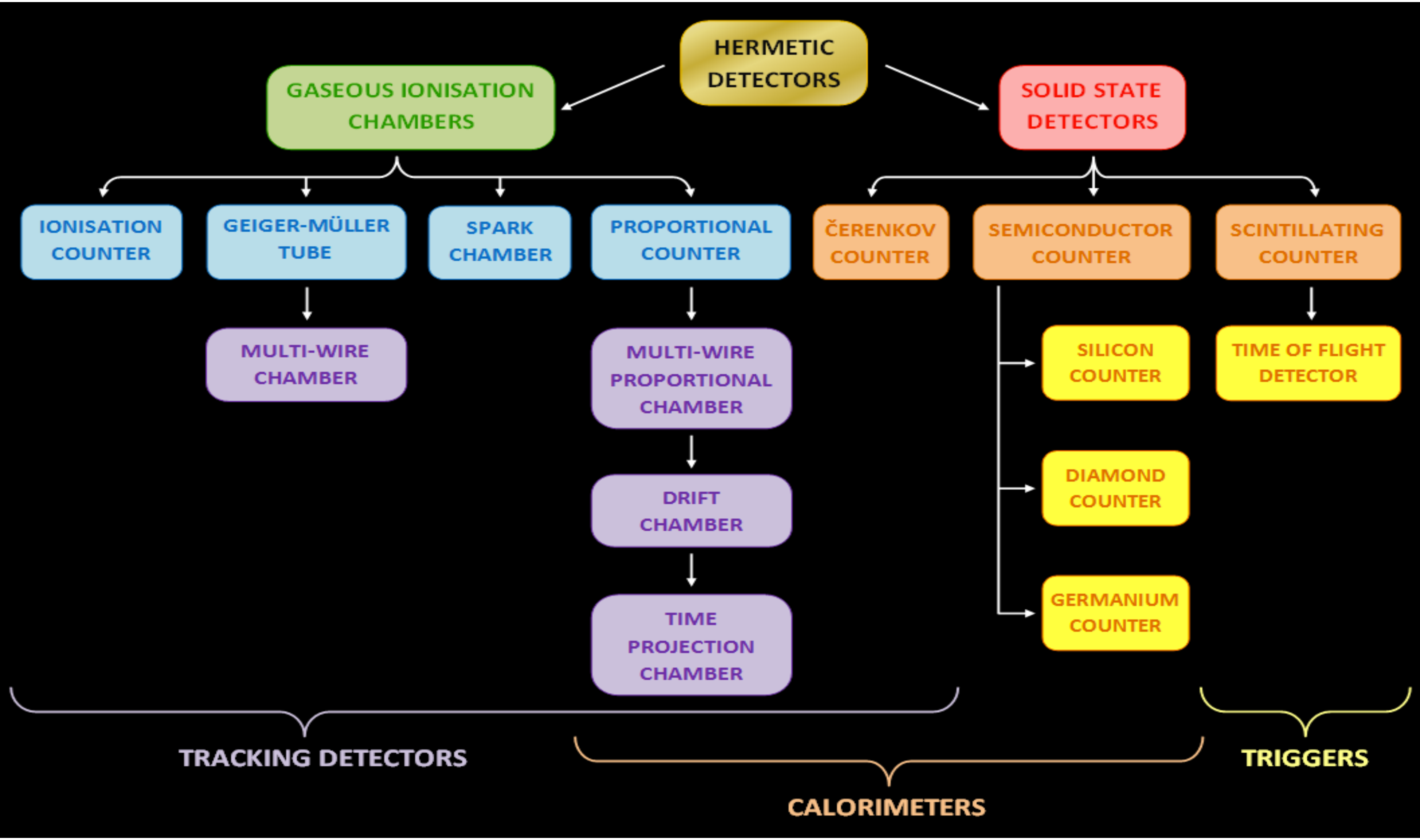
Types of Particle Detector

★ **Scintillators** : photons emitted by the excited atoms in transparent materials can be detected with photon detectors

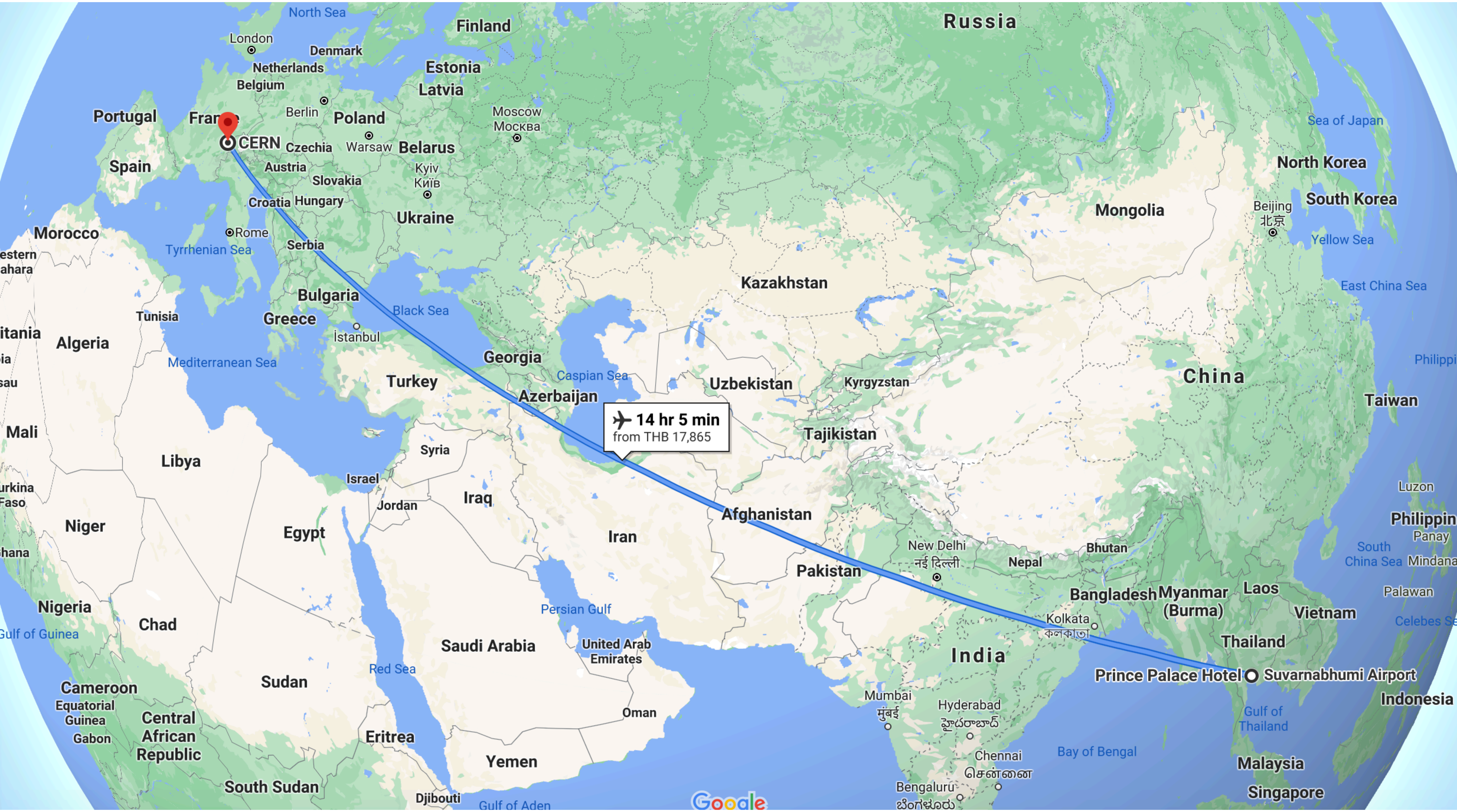


Detector Zoo

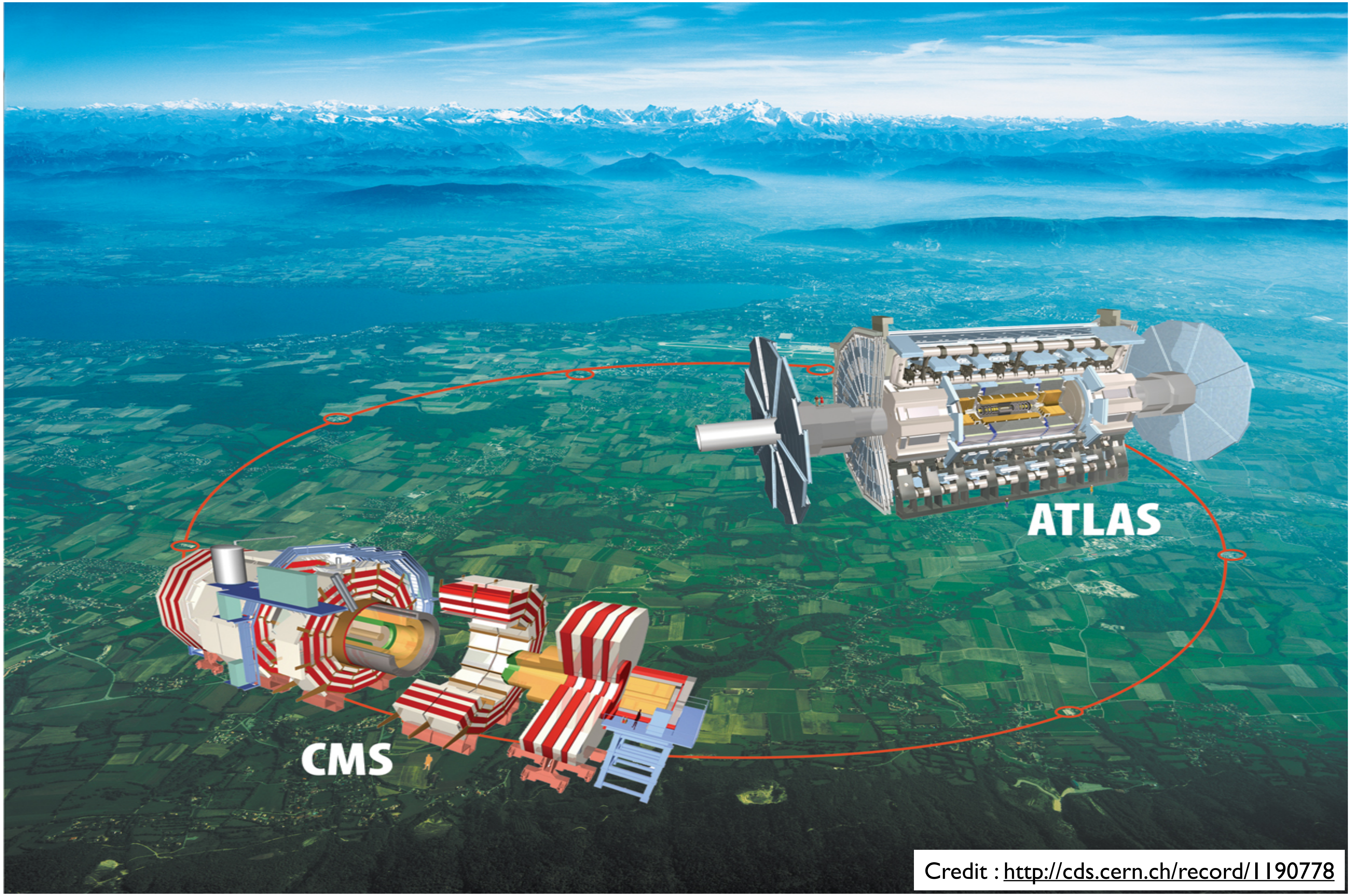
Credit : http://upload.wikimedia.org/wikipedia/commons/c/c0/Detectors_summary_3.png



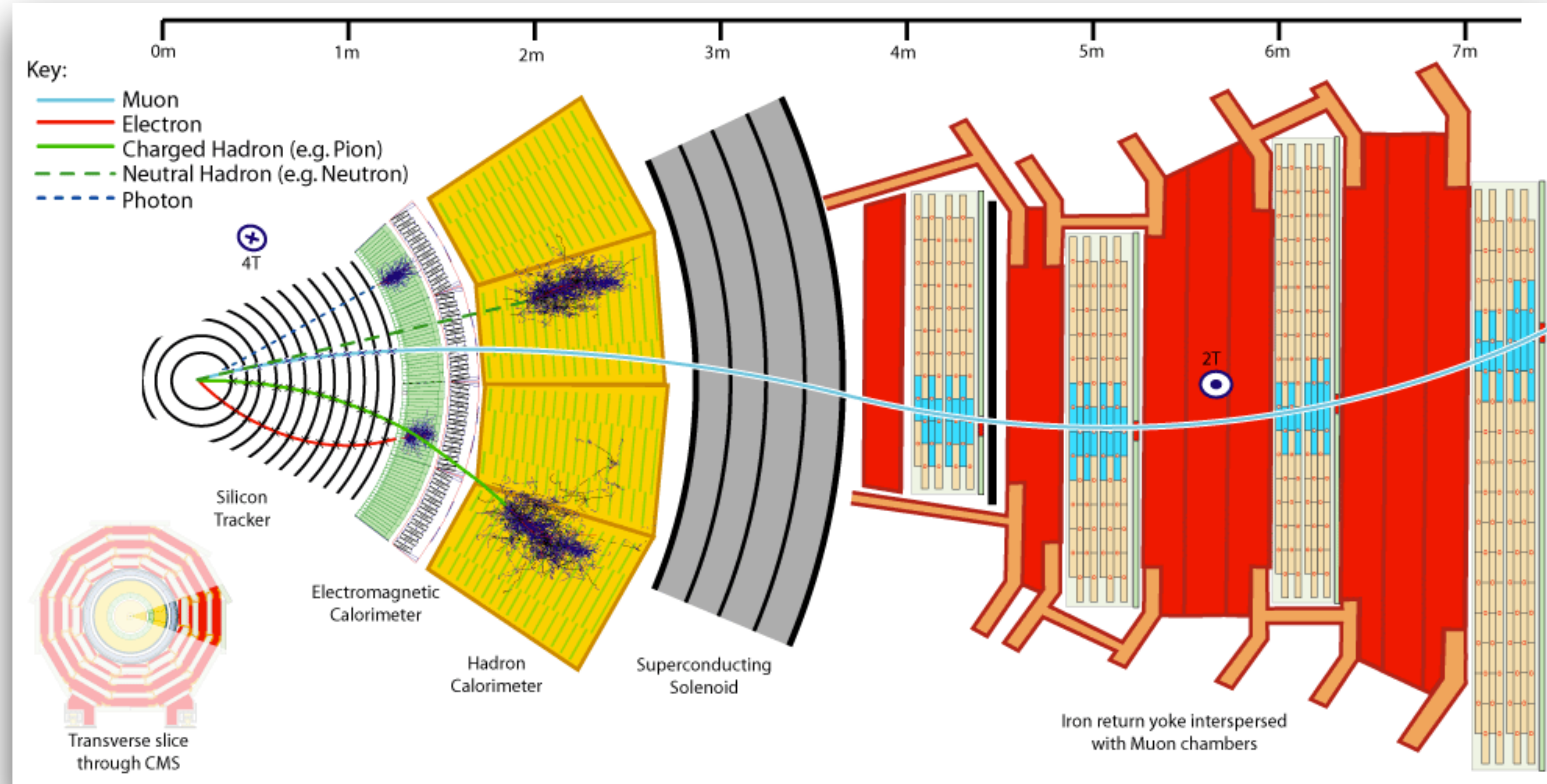
Dear Passengers…



LHC Experiments



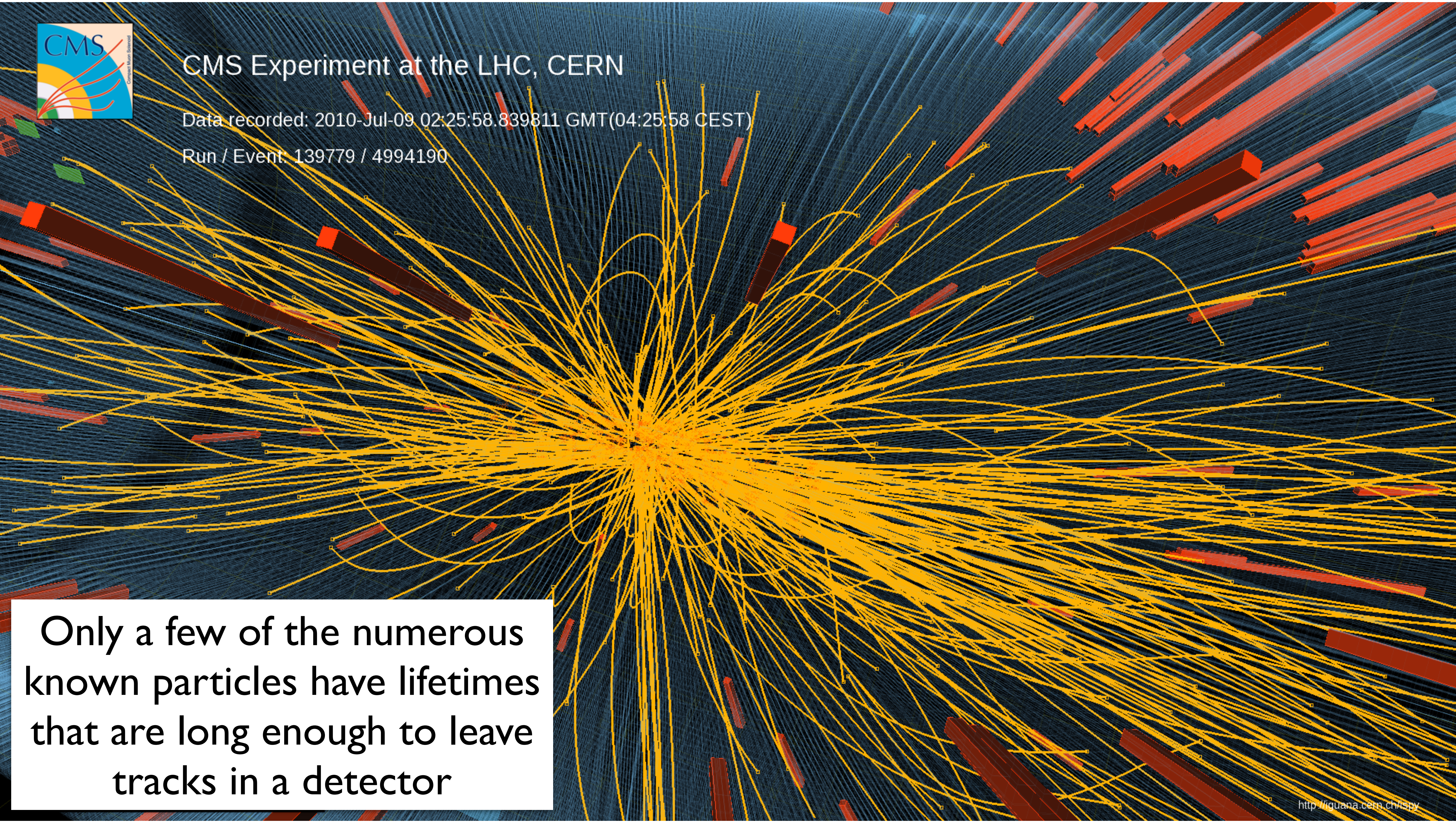
Particle Detection



★ Goal : to detect as many of the stable and long-lived particles produced in a particle collision

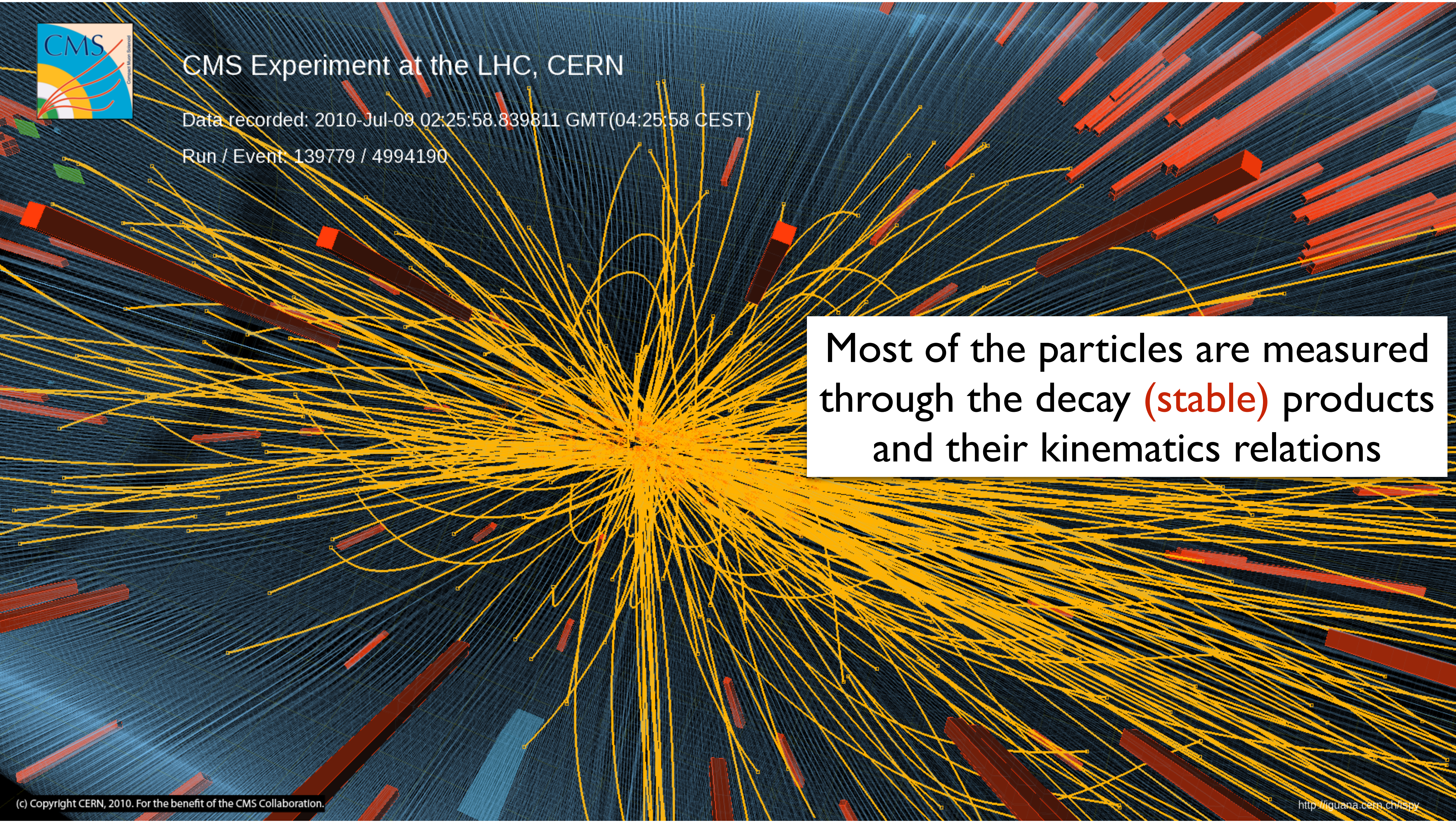
★ Need to measure : charge, mass, energy, direction

Particle from Collisions



Only a few of the numerous known particles have lifetimes that are long enough to leave tracks in a detector

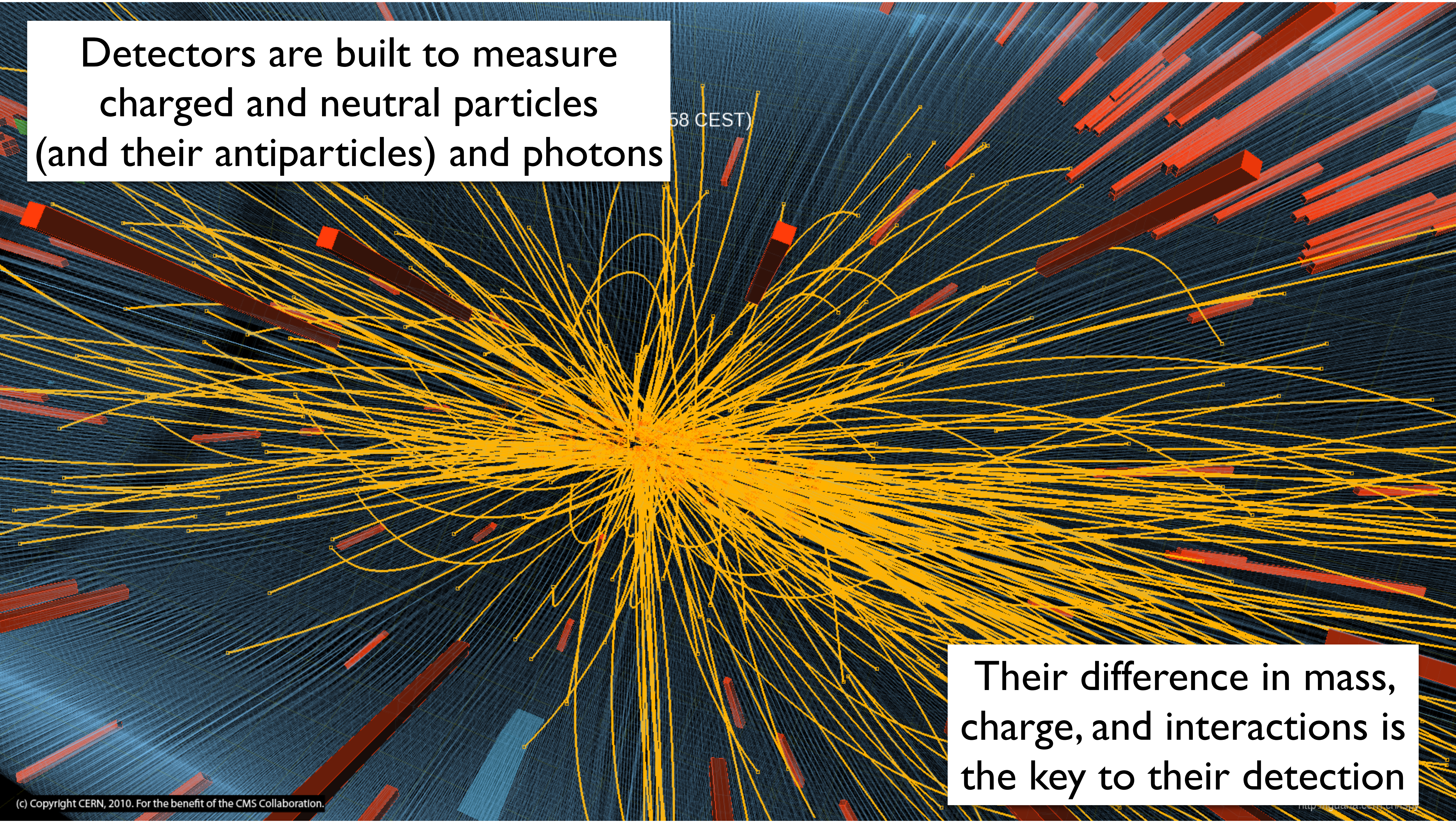
Particle from Collisions



Most of the particles are measured through the decay (stable) products and their kinematics relations

Particle from Collisions

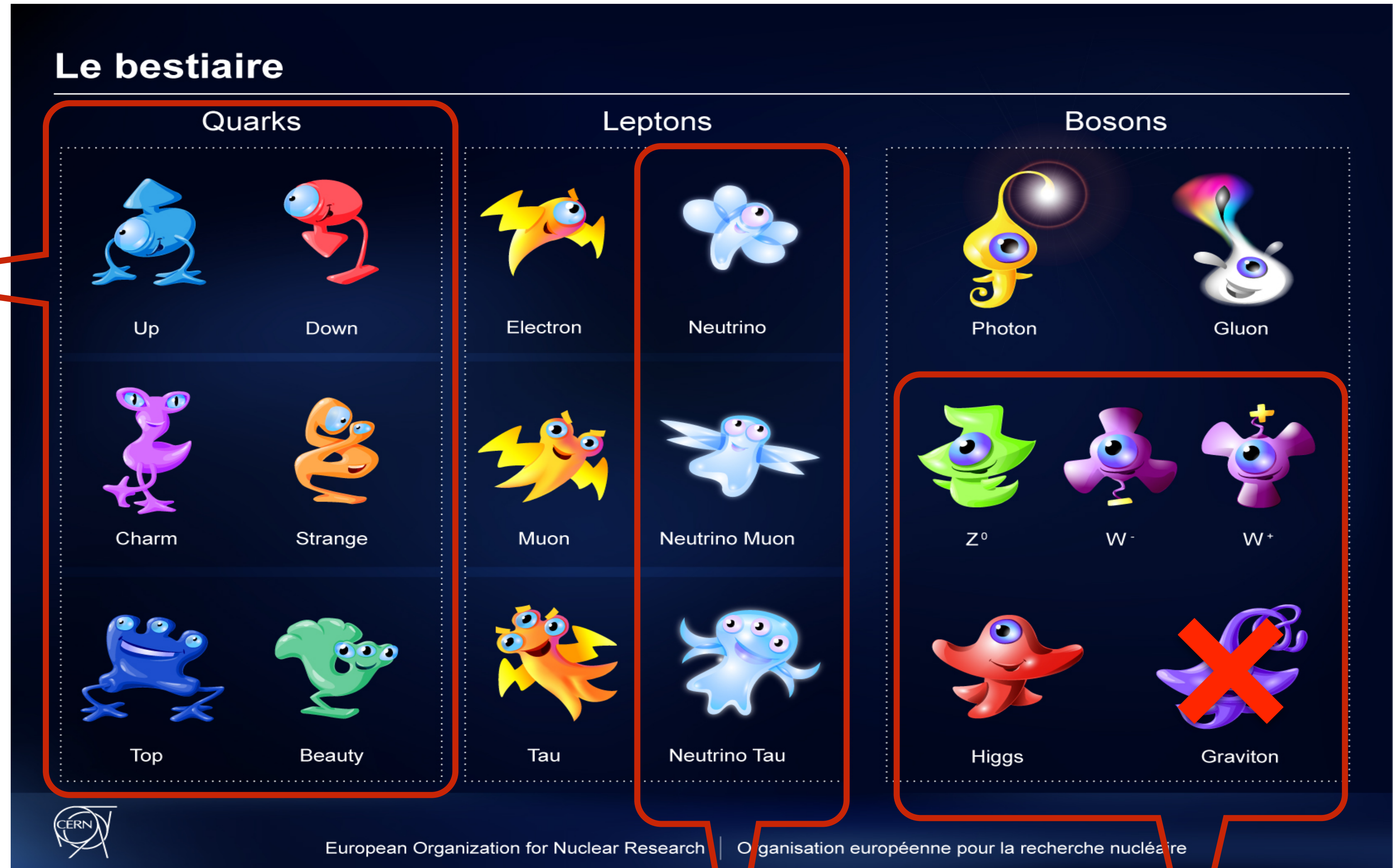
Detectors are built to measure charged and neutral particles (and their antiparticles) and photons



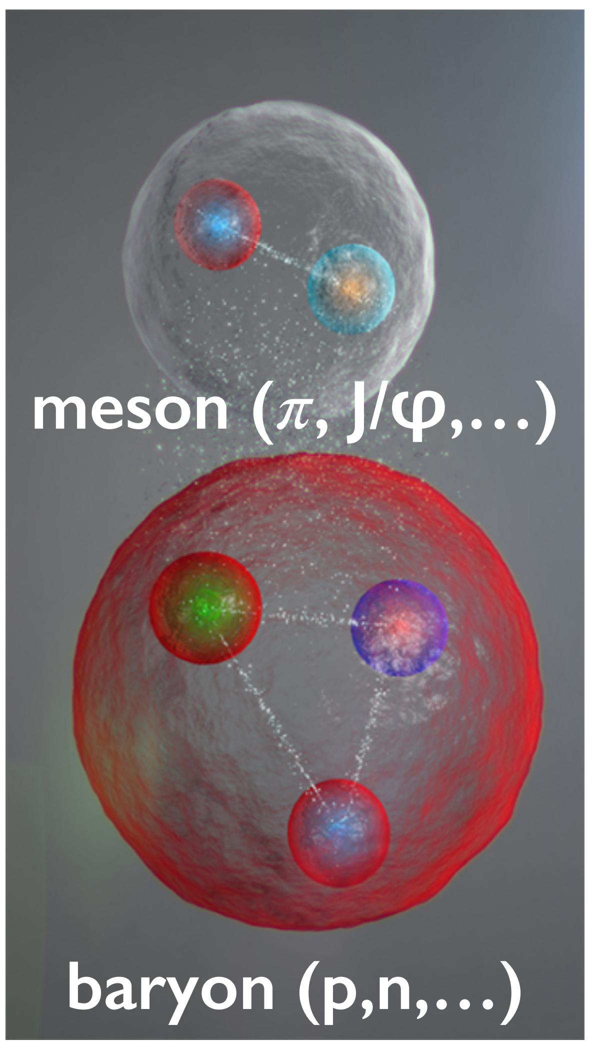
Their difference in mass, charge, and interactions is the key to their detection

Particle Zoo

Standard Model



Hadron



very weak interaction (require specific detector)

not so stable to be detected

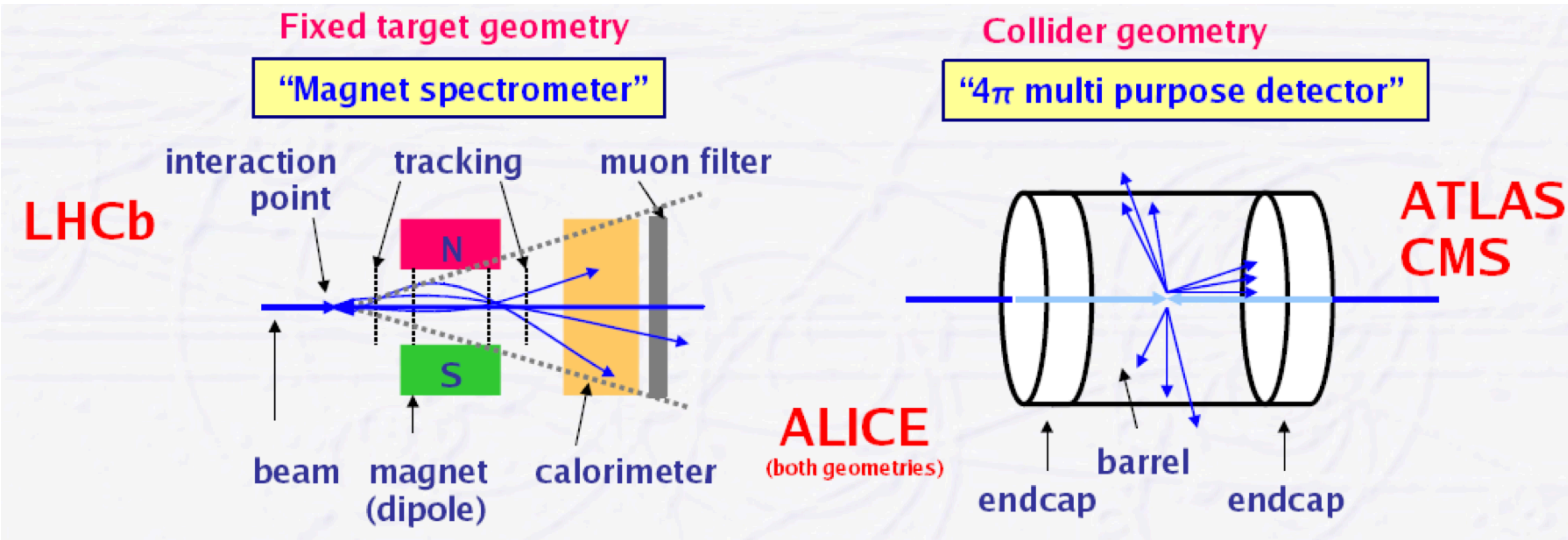
More details : https://pdg.lbl.gov/

Particle Detection

Ideal detector should allow to measure and identify all end products from the collision

- Charged leptons
  - electron : charged particle + electromagnetic interaction with matter
  - muon : charged particle + small interaction in matter (lifetime ~10^{-6}s)
  - tau : charged particle but lifetime ~2.10^{-17} s, reconstruct from decay products
- Photons : neutral particle + electromagnetic interaction in matter
- Hadrons (quarks/gluons not directly detected → jets)
  - Charged hadrons with (electromagnetic and nuclear) interaction in matter
  - Neutral hadrons with (nuclear) interaction in matter (special case of B hadrons with lifetime ~10^{-12} s)
- Neutrinos : no interaction in matter but deduced from energy/momentum conservation (missing energy)

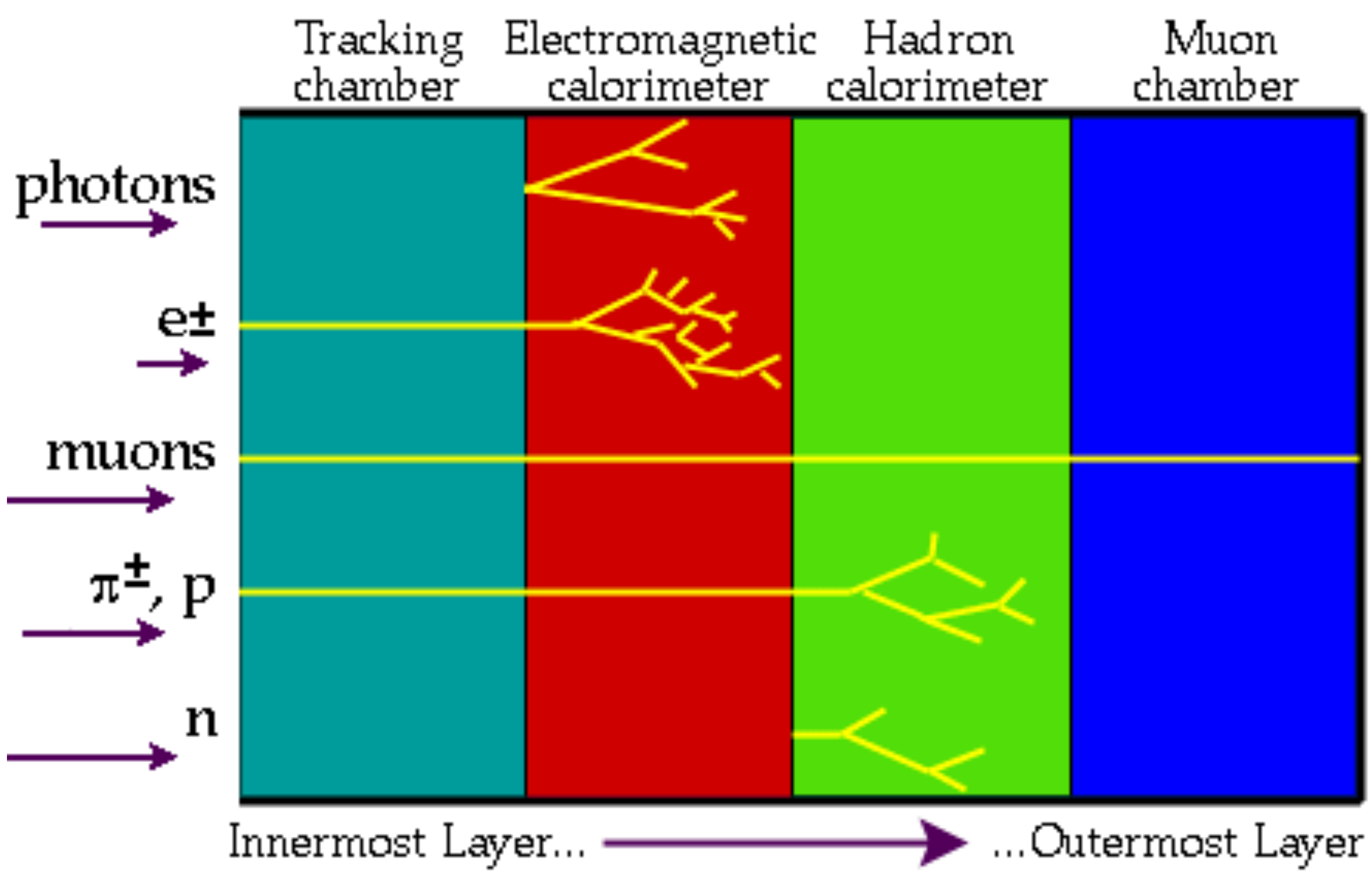
Detector Geometry

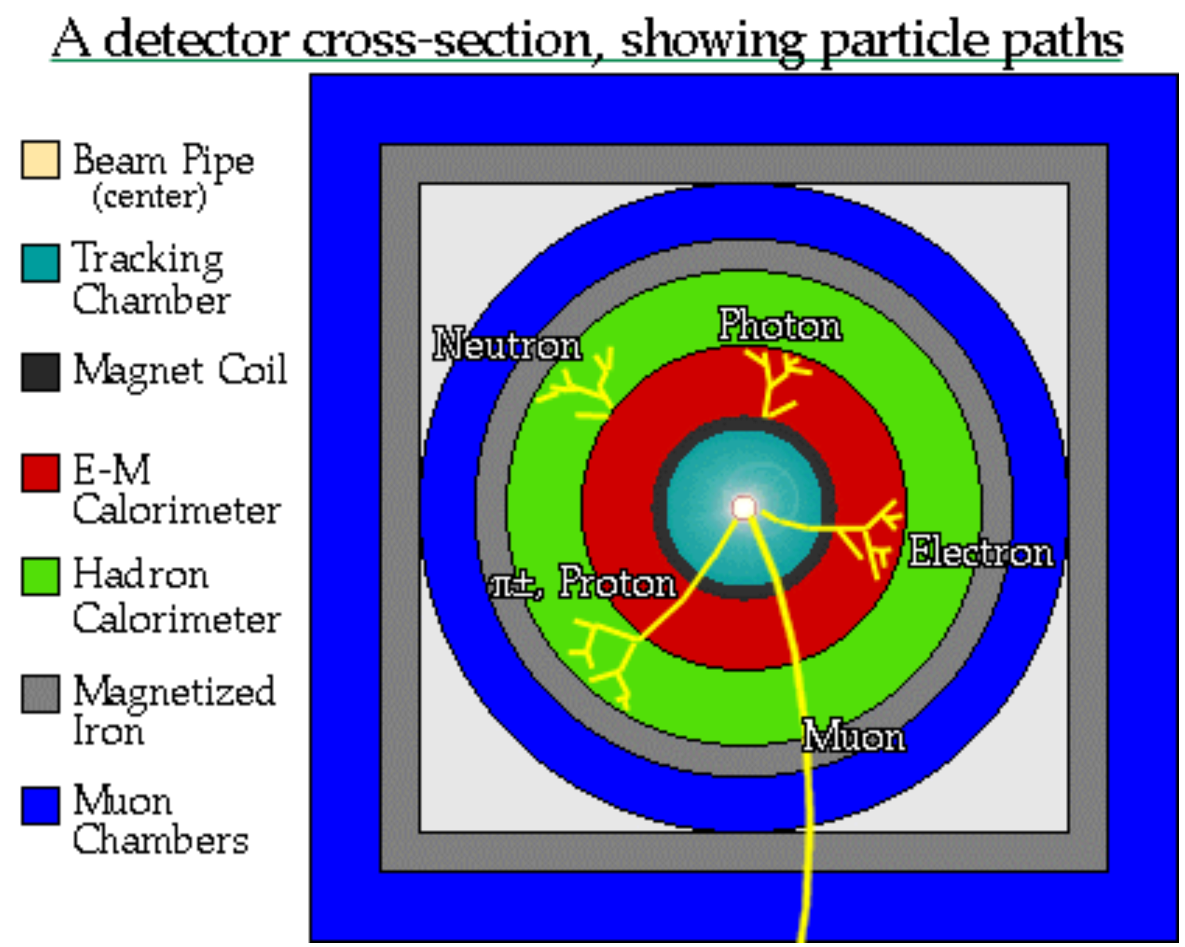


Look at collision products
in a small open angle
along beam axis
Plane detectors perpendicular to beam

Particles to be detected
over whole solid angle (4π)
Detectors arranged around
beam axis with "onion structure"

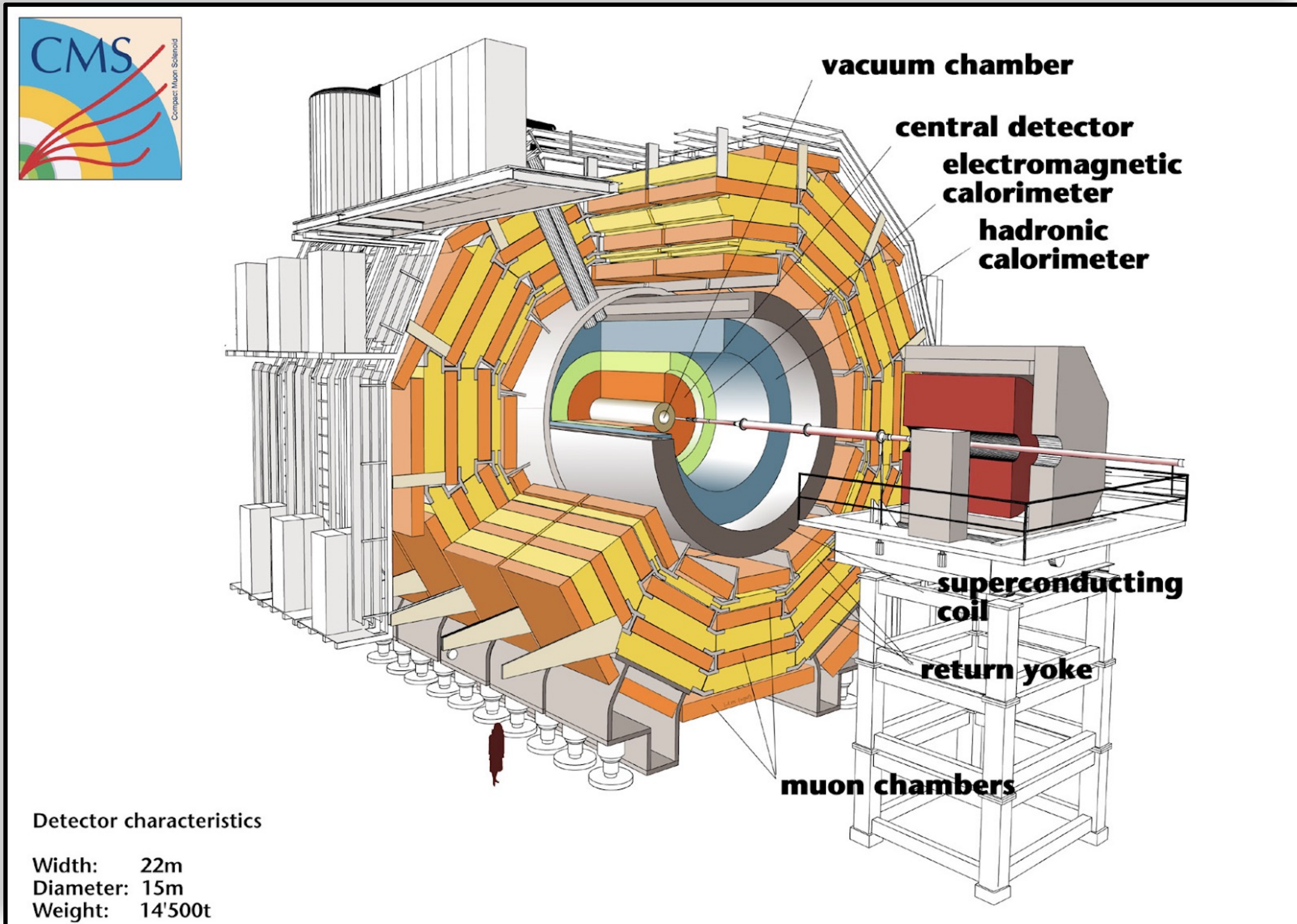
Generic HEP Detector



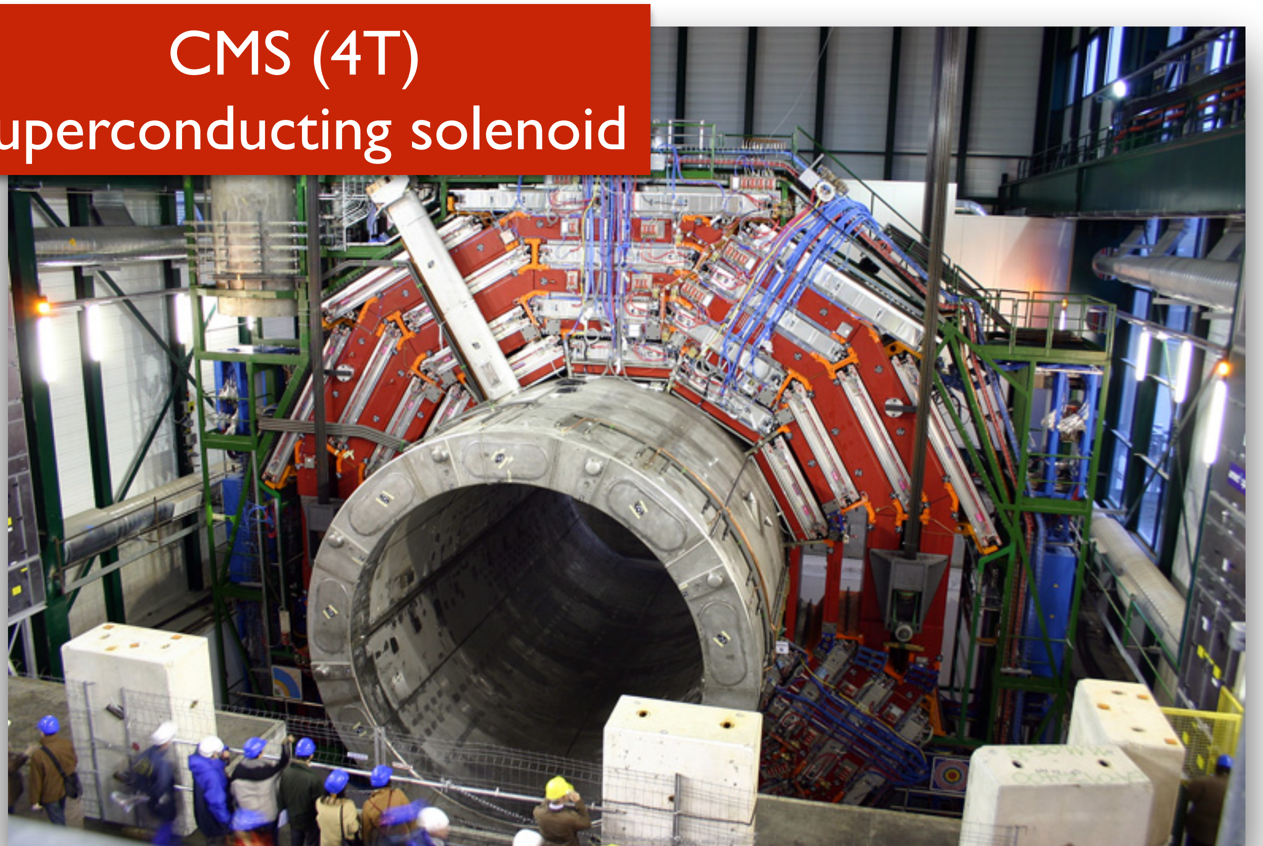


★ **Efficiency** : not all particles are detected, some leave the detector without any trace (neutrinos), some escape through not sensitive detector areas (holes, cracks for e.g. water cooling and gas pipes, cables, electronics, mechanics)

Multi-purpose Detector

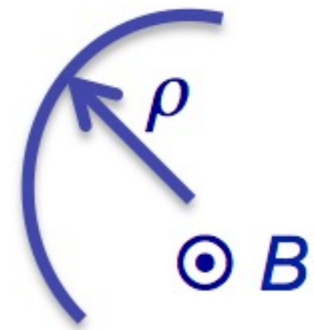


Magnetic Field - bending particles



CMS (4T)
Superconducting solenoid

★ Charged particles are deflected by magnetic field



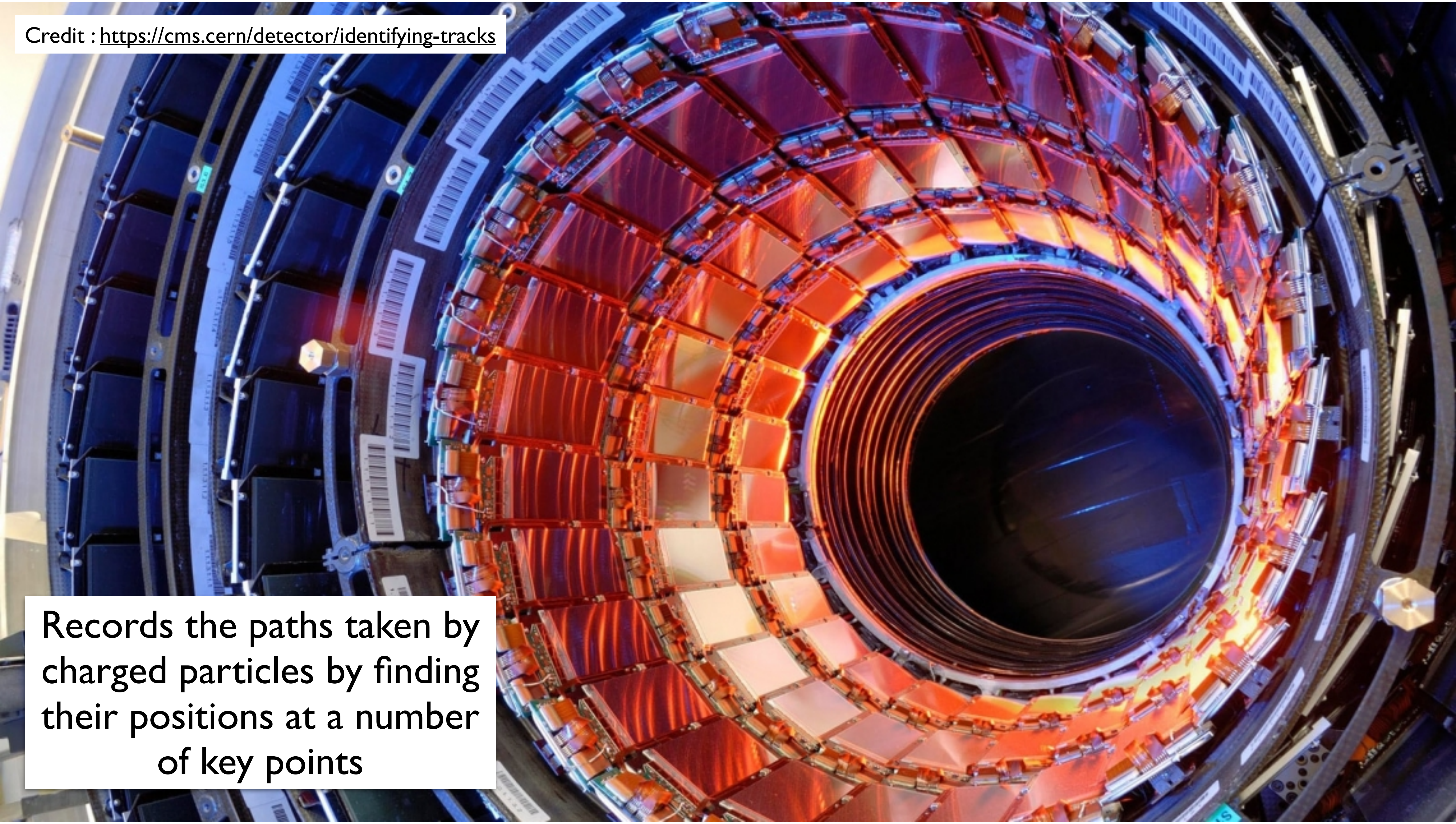
$$\rho = \frac{p_T}{q|B|} = \frac{\gamma m_0 \beta c}{q|B|}$$

★ By measuring the radius of curvature we can determine the momentum of a particle

★ If we can measure also β (velocity) independently we can determine the particle mass

ATLAS (3T)
Central solenoid
Barrel/Endcap Toroid

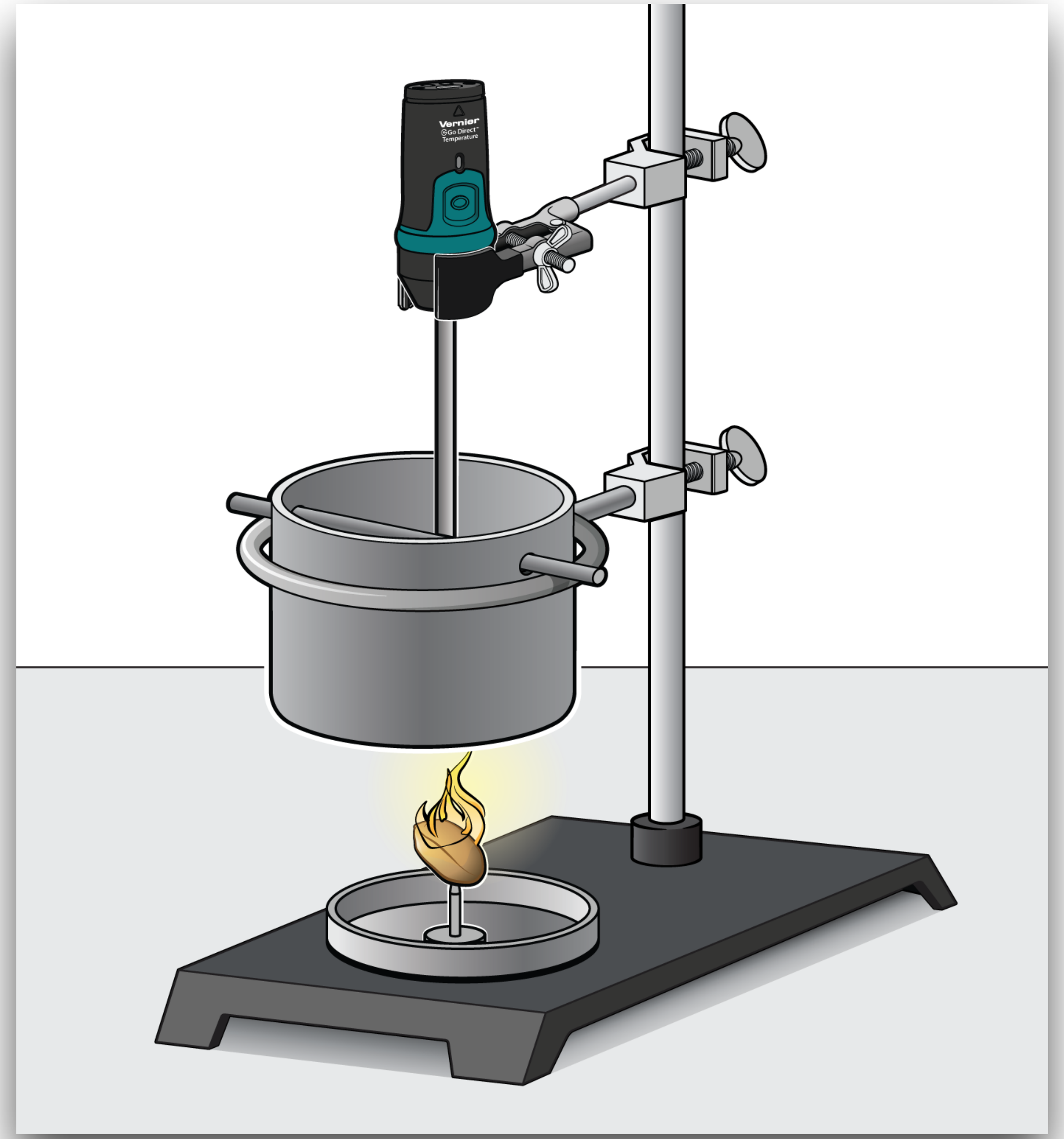
Tracker (solid state detector)



Calorimeter

★ How do we measure the energy in food?

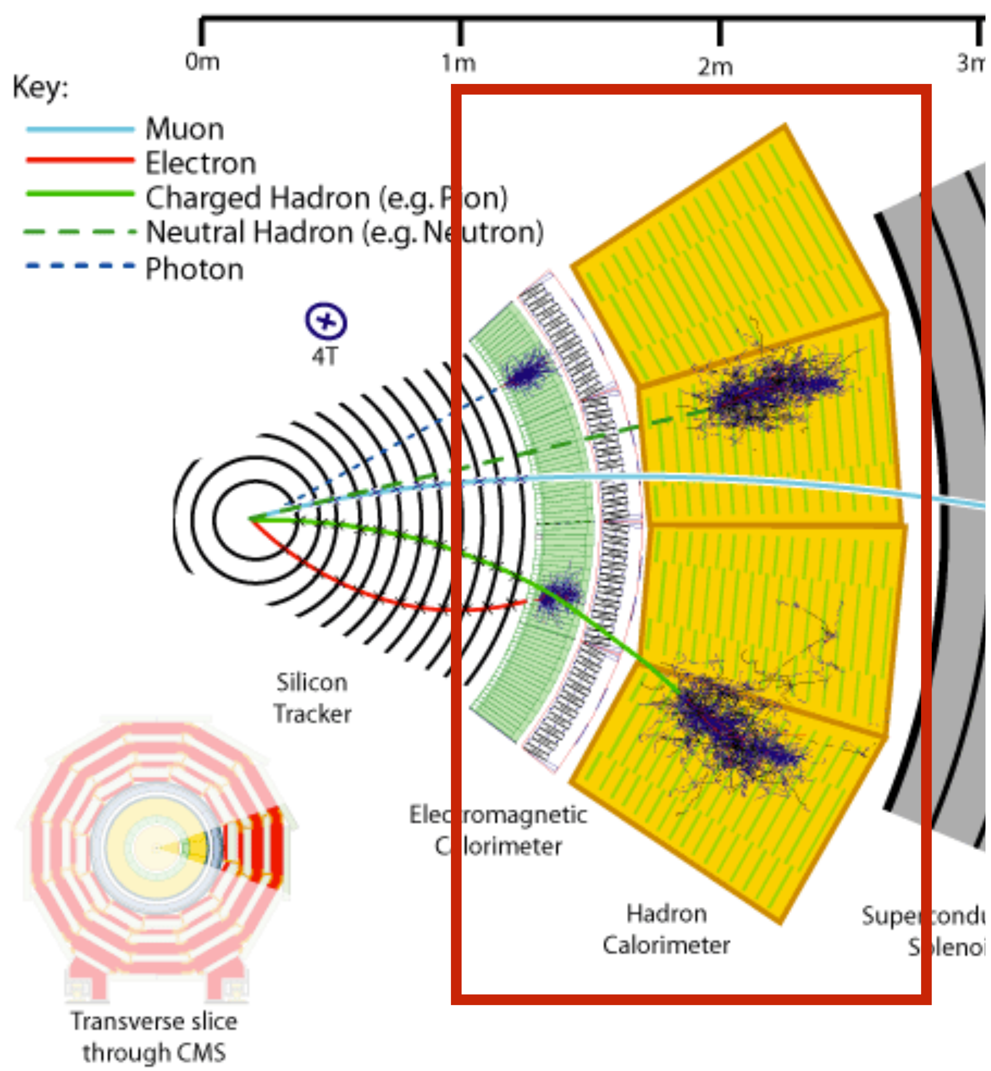
- “Burn food samples under a boiling tube containing a measured amount of water. Measure the temperature increases in the water. Calculate the amount of energy needed to cause that temperature increased. This gives an estimate of the amount of energy stored in the food” — Google



★ What is the concept behind this experiment?

- Release the food energy to boil water until the food is gone

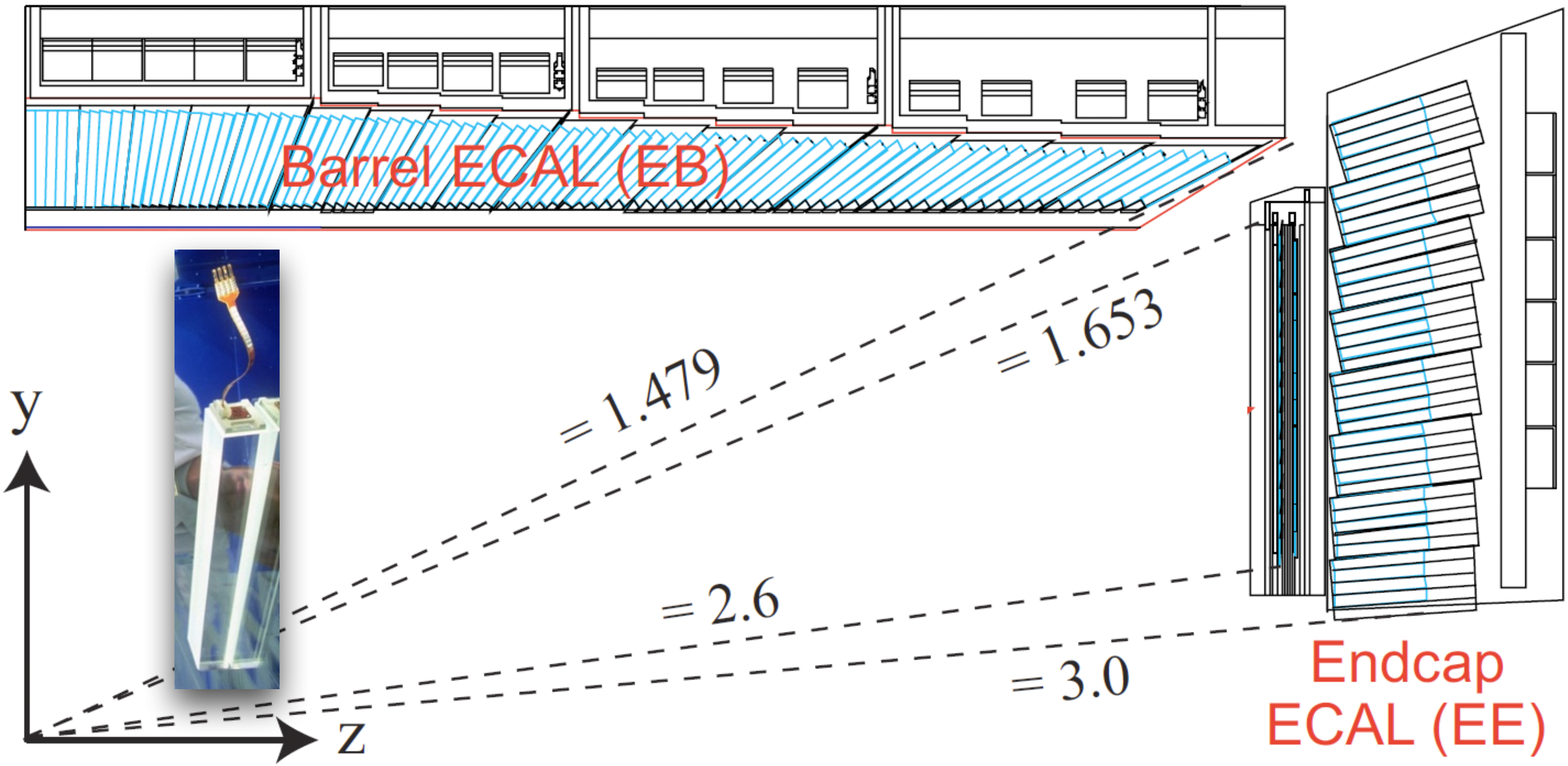
Calorimeter



- ★ In nuclear and particle physics calorimetry refers to the detection of particles through total absorption in a block of matter
- ★ The measurement process is destructive for almost all particles
- ★ The exception are muons (and neutrinos)
  - ◉ Identify muons easily since they penetrate a substantial amount of matter
  - ◉ In the absorption, almost all particle's energy is eventually converted to heat → calorimeter
  - ◉ Calorimeters are essential to measure neutral particles

Calorimeter — ECAL

★ Electromagnetic Calorimeter is the inner layer of the two and measures the energy of electrons and photons by stopping them completely

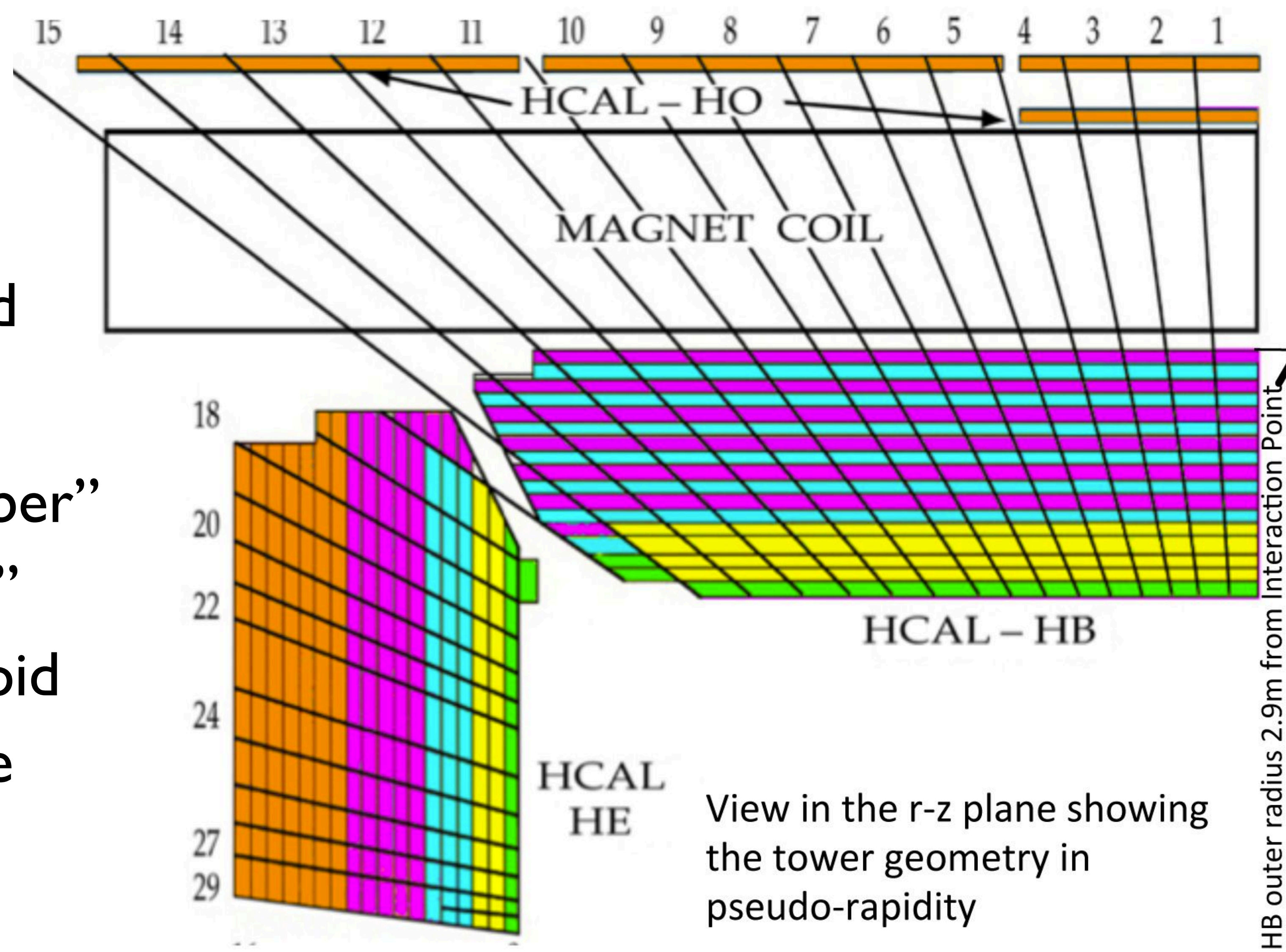


Calorimeter — HCAL

★ Hadrons, which are composite particles made up of quarks and gluons, fly through the ECAL and are stopped by the outer layer called the Hadron Calorimeter (HCAL)

★ Most of HCAL is a sampling calorimeter (material that produces the particle shower is distinct from the material that measures the deposited energy)

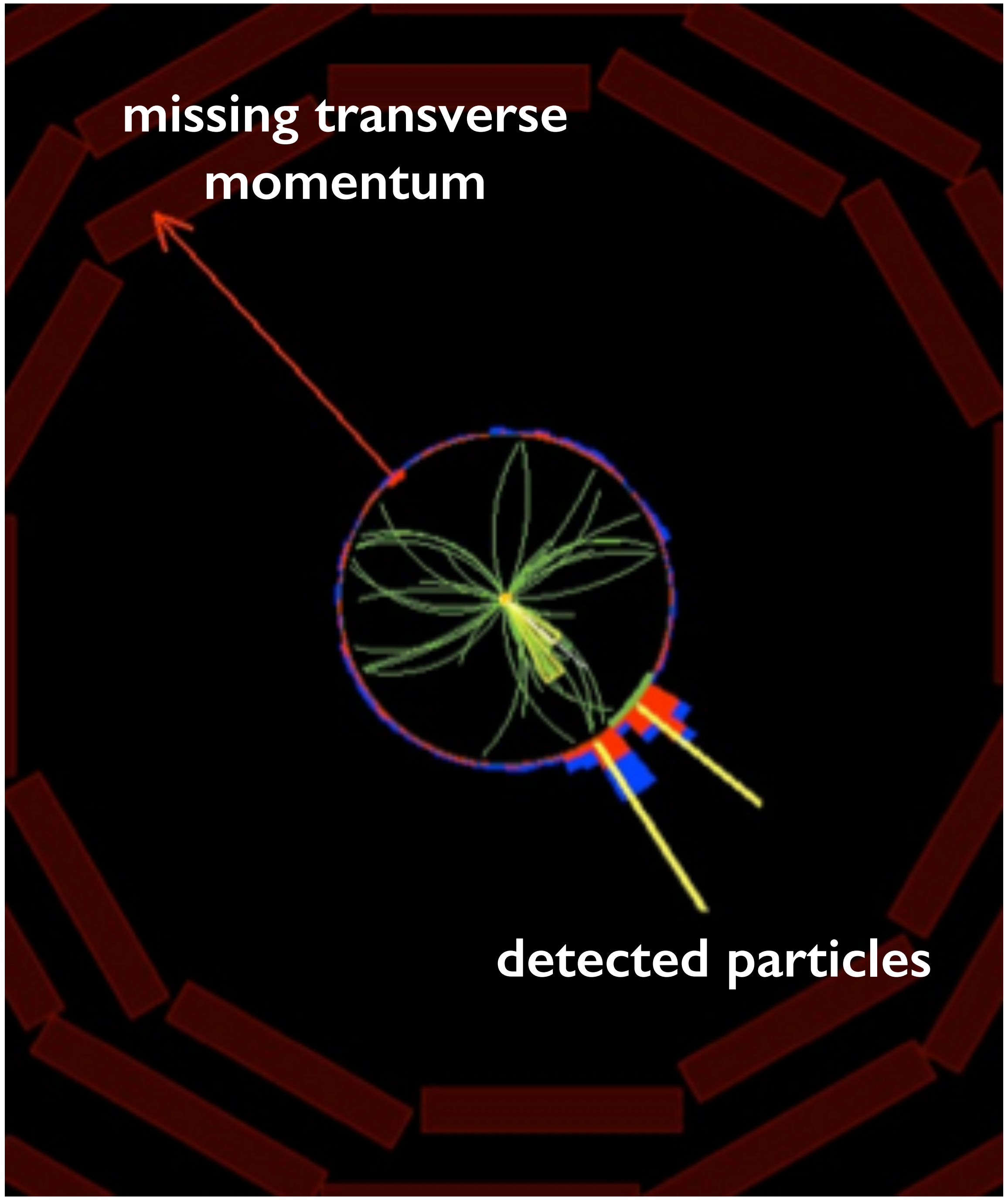
★ Alternating layers of "absorber" and fluorescent "scintillator" materials that produce a rapid light pulse when the particle passes through



View in the r-z plane showing the tower geometry in pseudo-rapidity

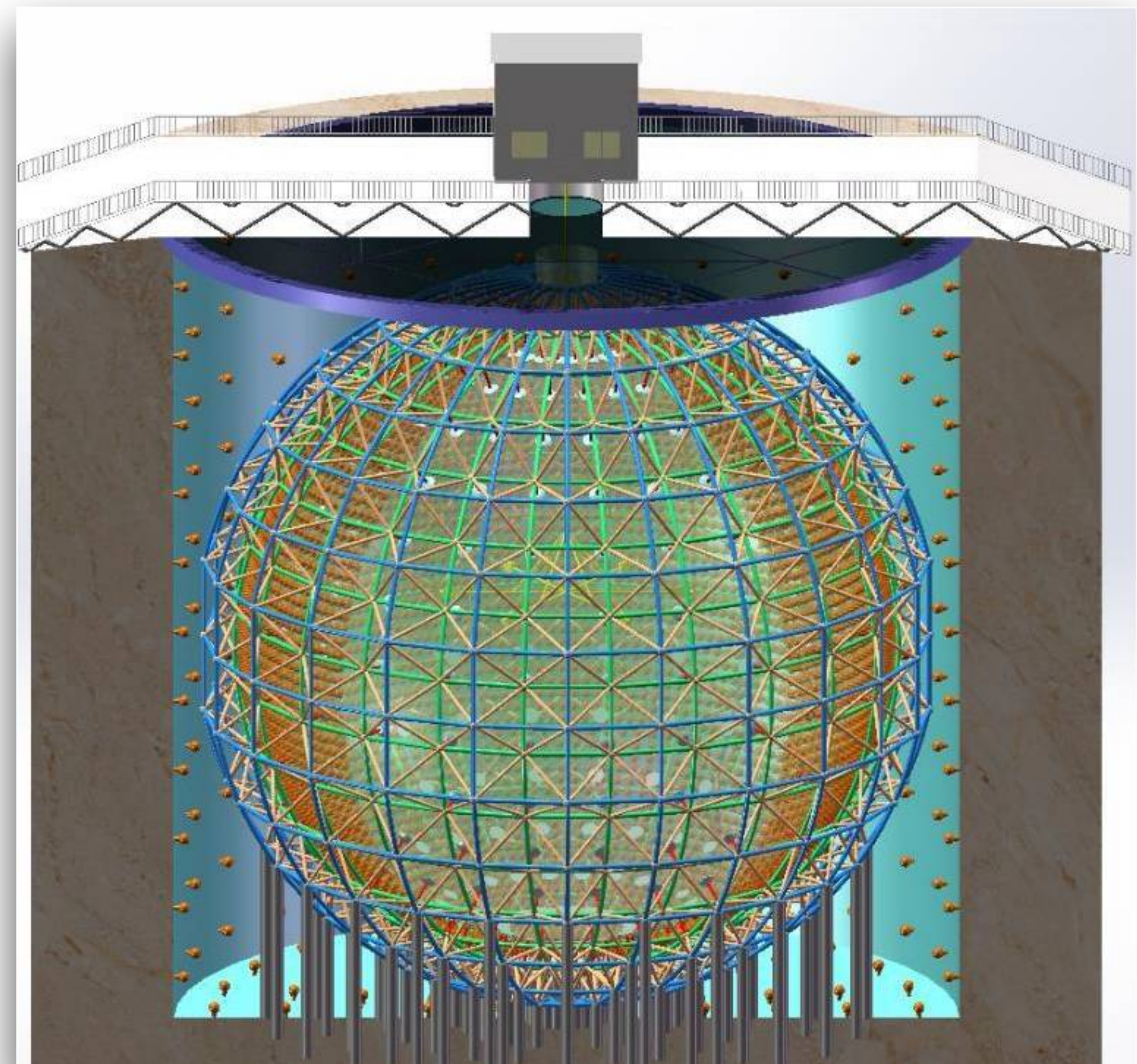
Any Undetected Particles?

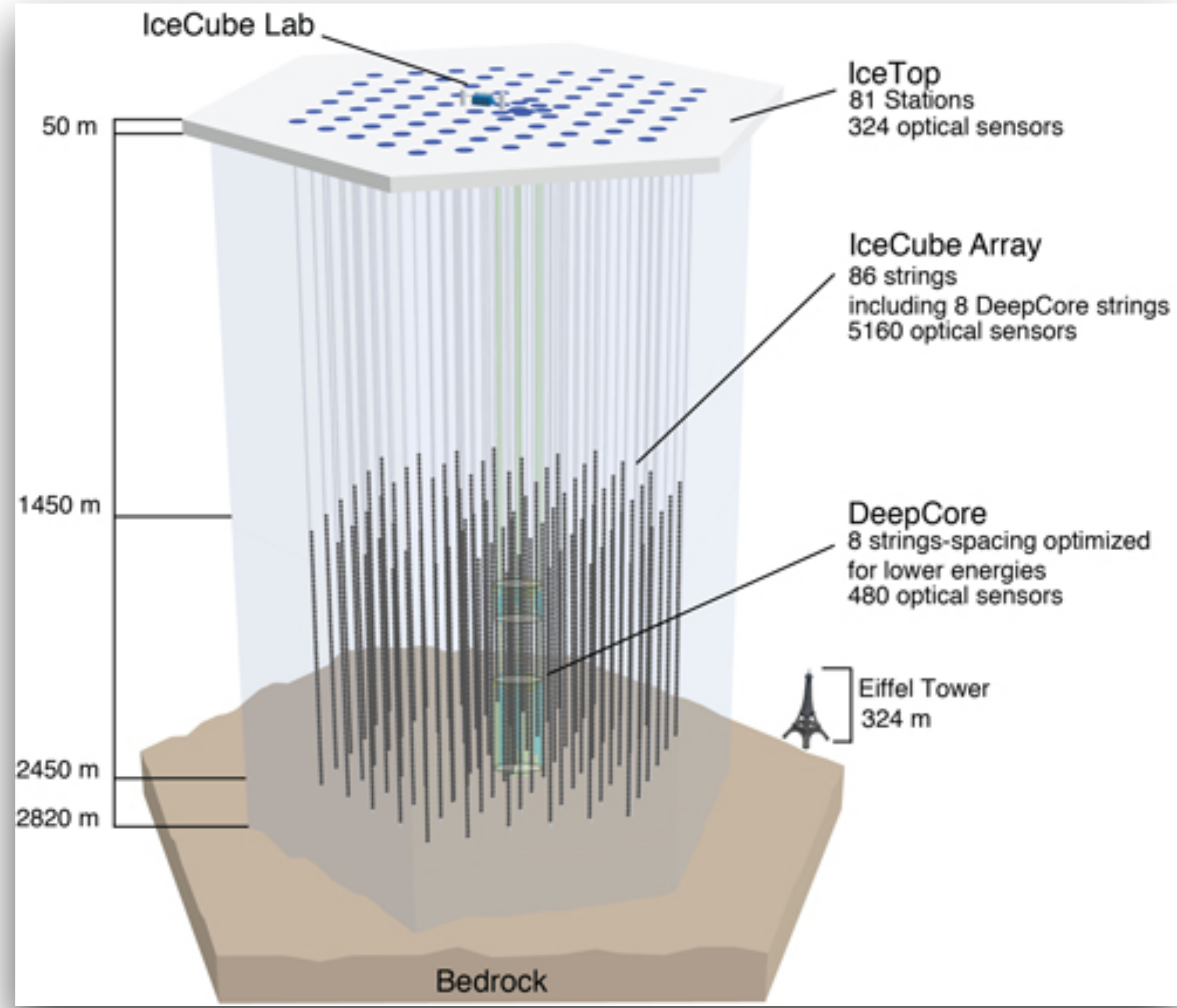
- ★ Onion-like shape detector to avoid missing particles but still…
- ★ In collider experiment, we detect this kind of particle indirectly from the momentum imbalance in the plane perpendicular to the beam direction. This quantity known as **missing transverse momentum**
- ★ What we do is summing up all visible energy and momentum, then attribute missing energy and momentum to neutrino or undetected particles.



Neutrino Experiments

JUNO Experiment (under construction)

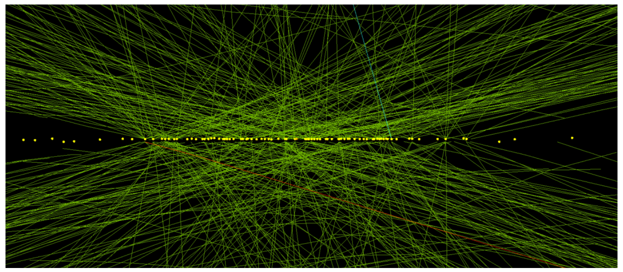




IceCube Experiment (2010 - present)

Credit : https://neutel11.wordpress.com/2015/03/04/j-cao-juno-a-multi-purpose-neutrino-observatory/
https://en.wikipedia.org/wiki/IceCube_Neutrino_Observatory

Trigger and Event Selection



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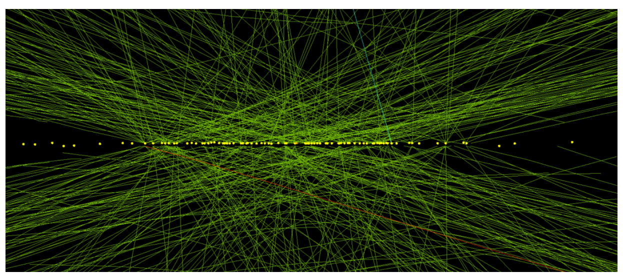

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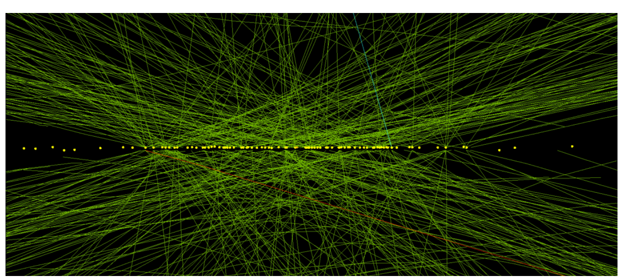

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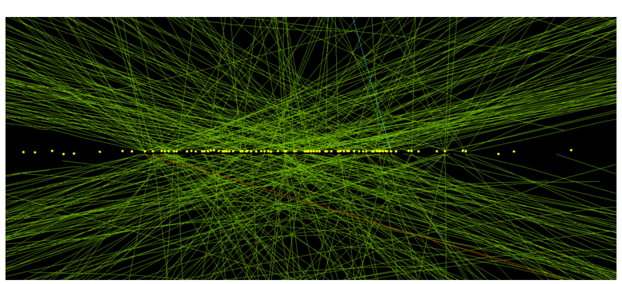


↓ 25

★ Collision every 25 ns (40M events per sec)

- ~2 MB/events
- 80 TB/sec

Impossible for storage and CPU to process all events

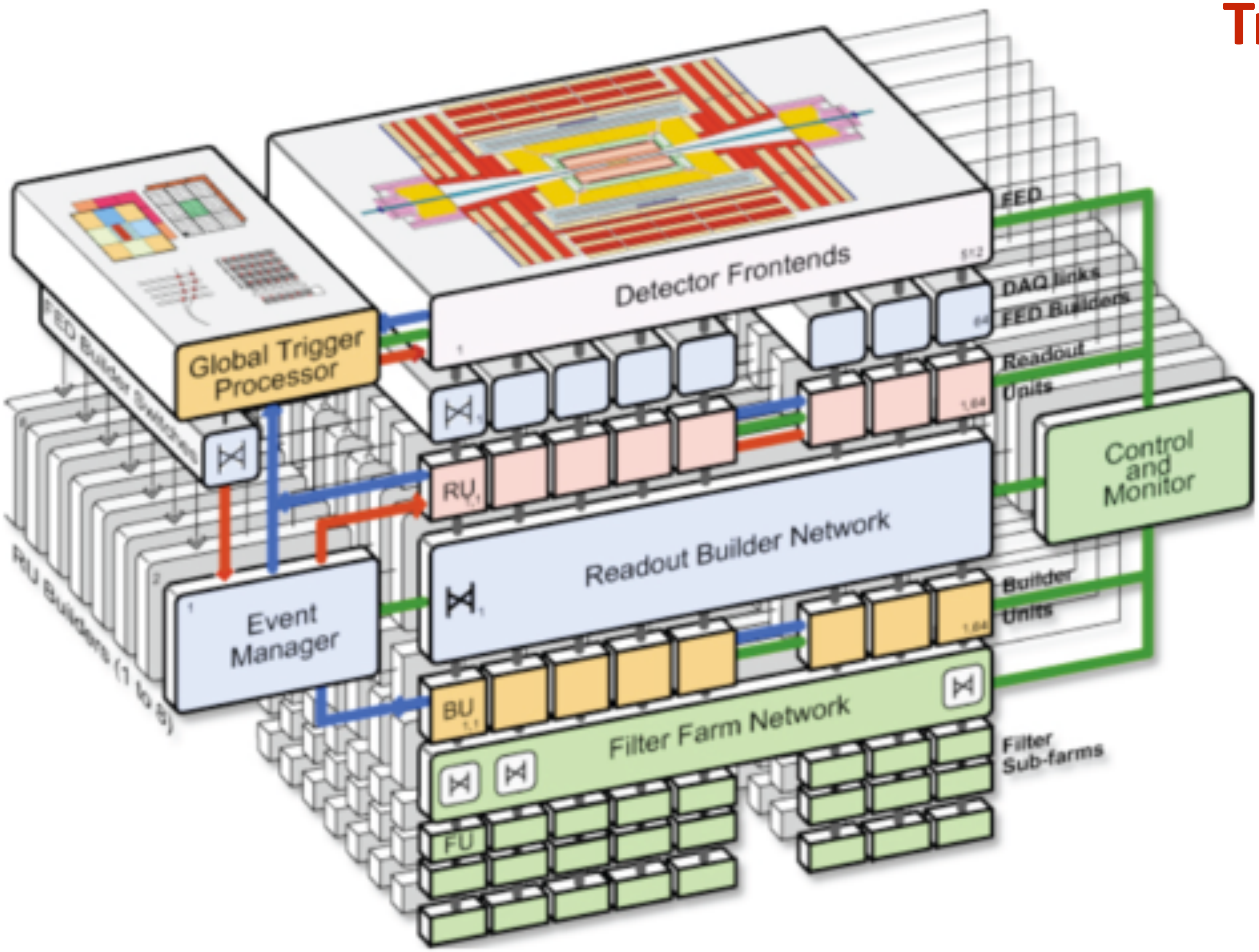
★ We need pre-selection based on physics of interest

- ➡ i.e. Higgs decay modes (e.g. H to ZZ to 4mu)
- ➡ look for "stable" products, i.e. lifetime is larger enough and those particles interact with detector

★ Trigger system

- ➡ Electronics
- ➡ Computing (full pictures of collision)

Trigger and Event Selection

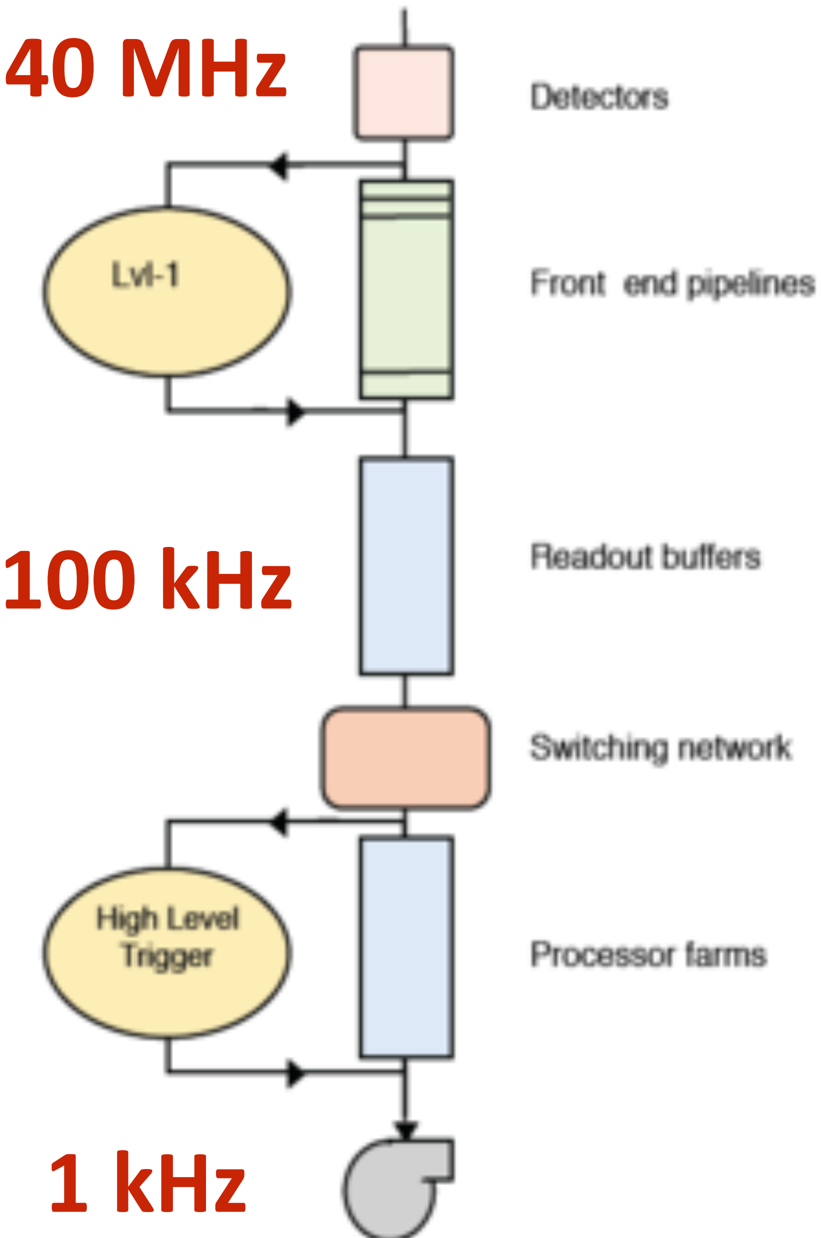


Trigger Rate

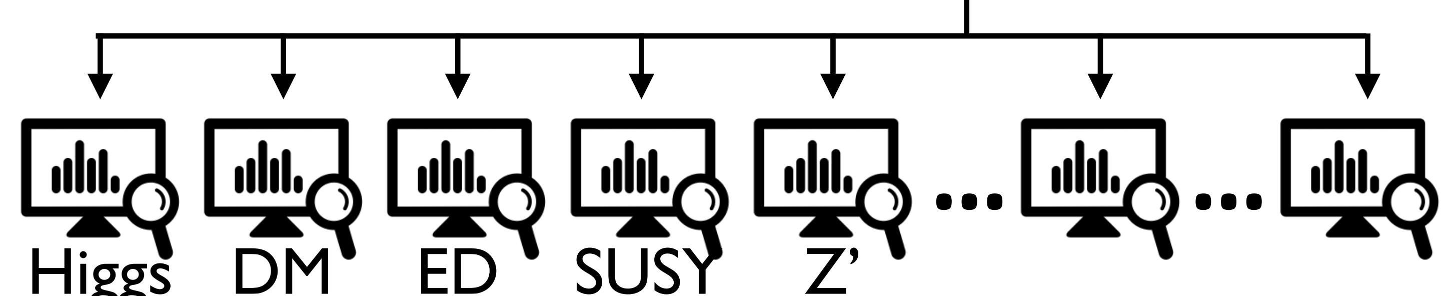
40 MHz

100 kHz

1 kHz

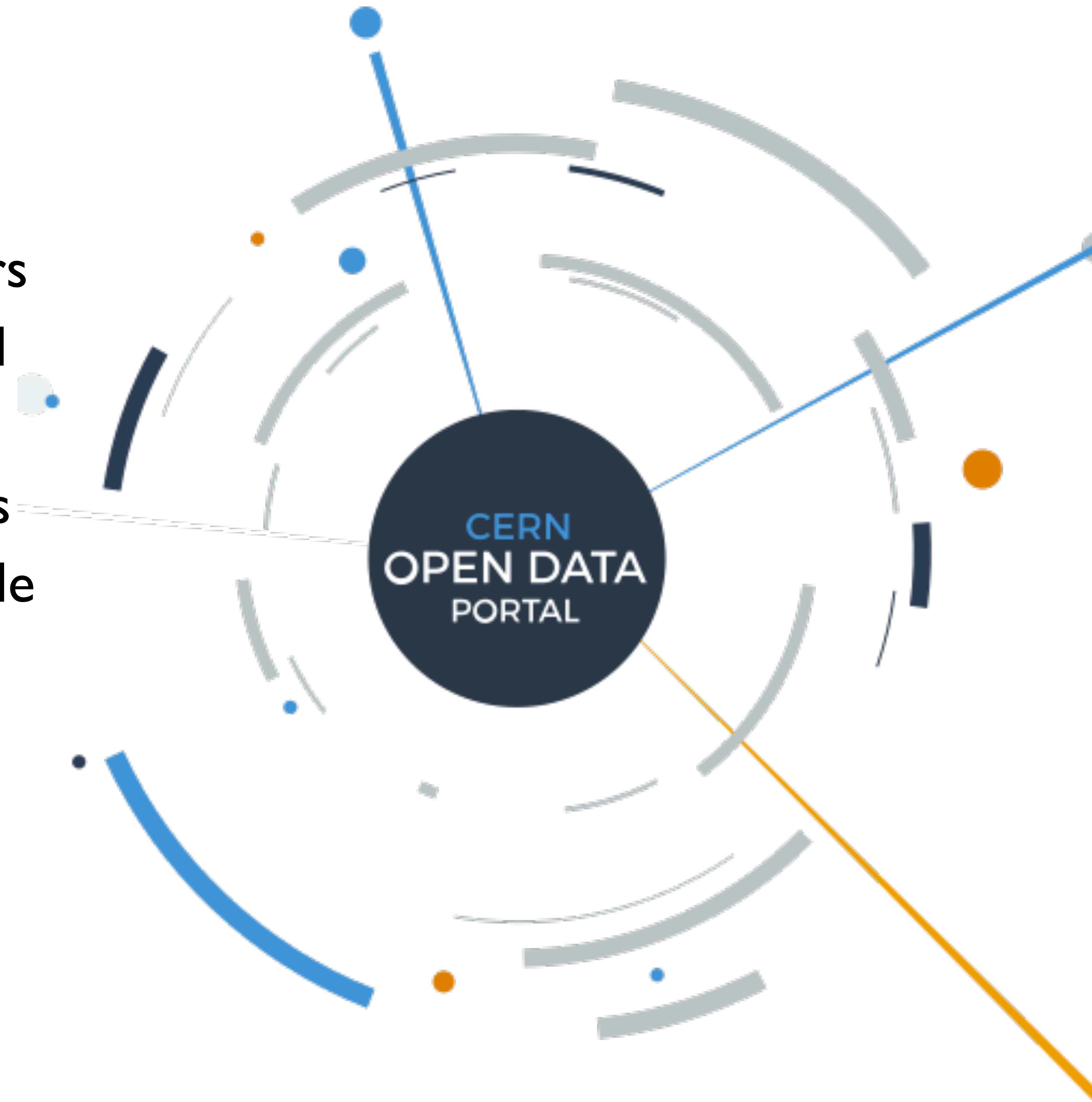


We need
- ➡ fast electronic devices,
- ➡ fast computing algorithms



CERN Open Data

- ★ **CERN Open Data** provides content for both education and research. CERN aims to support high-school students and teachers as well as university students and professors. Detailed guides will introduce you to physics analyses that make use of datasets available from this portal. Event displays allow you to visualise collision data and examine what happens when particles interact in high-energy collisions.
- ★ http://opendata.cern.ch/



Acknowledgement